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Geology of the Lassen Peak district

by

J. S. Diller

Extract from the Eighth Annual Report of the Director, 1886-'87

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Government Printing Office
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GEOLOGY

OF THE

LASSEN PEAK DISTRICT.

BY

J. S. DILLER.

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GEOLOGY OF THE LASSEN PEAK DISTRICT.

By J. S. Diller.

INTRODUCTION.

The geological survey of the Cascade Range, under the direction of Capt. C. E. Dutton, was commenced in 1883. At that time the writer was sent out to make a general reconnaissance of the range in the northern part of California and Oregon. A party outfitted at Red Bluff, and after ascending Lassen Peak and Mt. Shasta proceeded northward through Oregon along the eastern base of the range. From this line of travel detours were made to examine the summit of the range at Crater Lake, Mt. Scott, Union Peak, Mt. Thielson, Diamond Peak, and the Three Sisters. Crossing the range at Mt. Hood, the party returned along its western base to California. Since then three field seasons have been devoted to the study of volcanic phenomena in the vicinity of Mt. Shasta and Lassen Peak.

The preliminary survey of the Cascade Range clearly indicated that the point at which to begin a study of its details was in the vicinity of Lassen Peak. This locality was considered of particular interest on account of the great variety of its lavas, the recency of some of its volcanic eruptions, and the vigorous solfataric action which still survives. It was anticipated also that a careful study of this region would solve one of the perplexing geographic problems of the Pacific coast, viz., the relations between the Coast, Cascade, and Sierra Nevada Ranges.

The district has been found replete with a great variety of interesting phenomena, only part of which can be discussed at present. This initial report will be restricted to a consideration of the geologic history of the region as chronicled in its stratified deposits. Special reference will be made to the development of the Sierra Nevada Range and the relation of its great structural features to the volcanic phenomena in the vicinity of Lassen Peak, leaving the particular discussion of the latter for another occasion.

HYPSOGRAPHY.

GENERAL HYPSOGRAPHIC FEATURES.

The belt of country lying between the Great Basin and the Pacific may be regarded as grouped naturally into two valleys and three mountain ranges. The Coast Range is separated from the Cascade upon the north by the valley of the Willamette, and upon the south from the Sierra Nevada by the broad depression drained by the Sacramento. Near the State line between Oregon and California the three ranges meet in common ground, among a group of ridges and peaks so complex as apparently to render the definition of the ranges a matter of considerable difficulty. It is true, nevertheless, that each range is sharply characterized by its geologic development, and everywhere within this mountain plexus its limits are clearly defined.

HYPSOGRAPHY OF THE LASSEN PEAK DISTRICT.

The position and boundaries of the Lassen Peak district are represented in Fig. 13. Its primary hypsographic features are the volcanic ridge, the Piedmont, and the Great Basin platform, all of which are outlined on the accompanying illustration (Pl. XLV). Lassen Peak stands in the midst of a belt of volcanic cones stretching from the

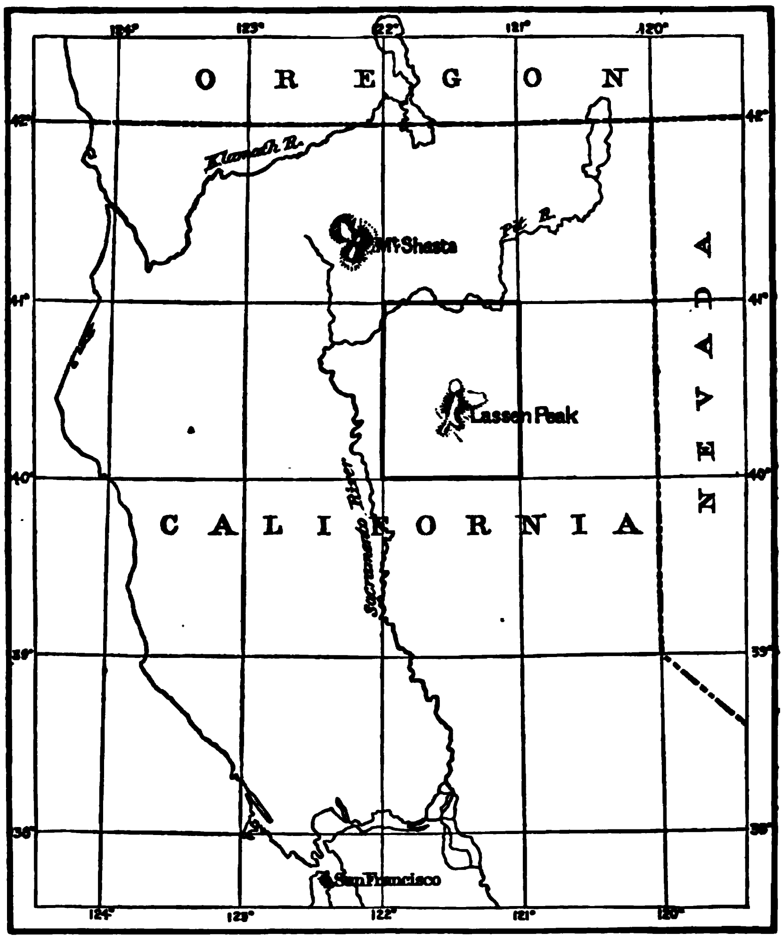
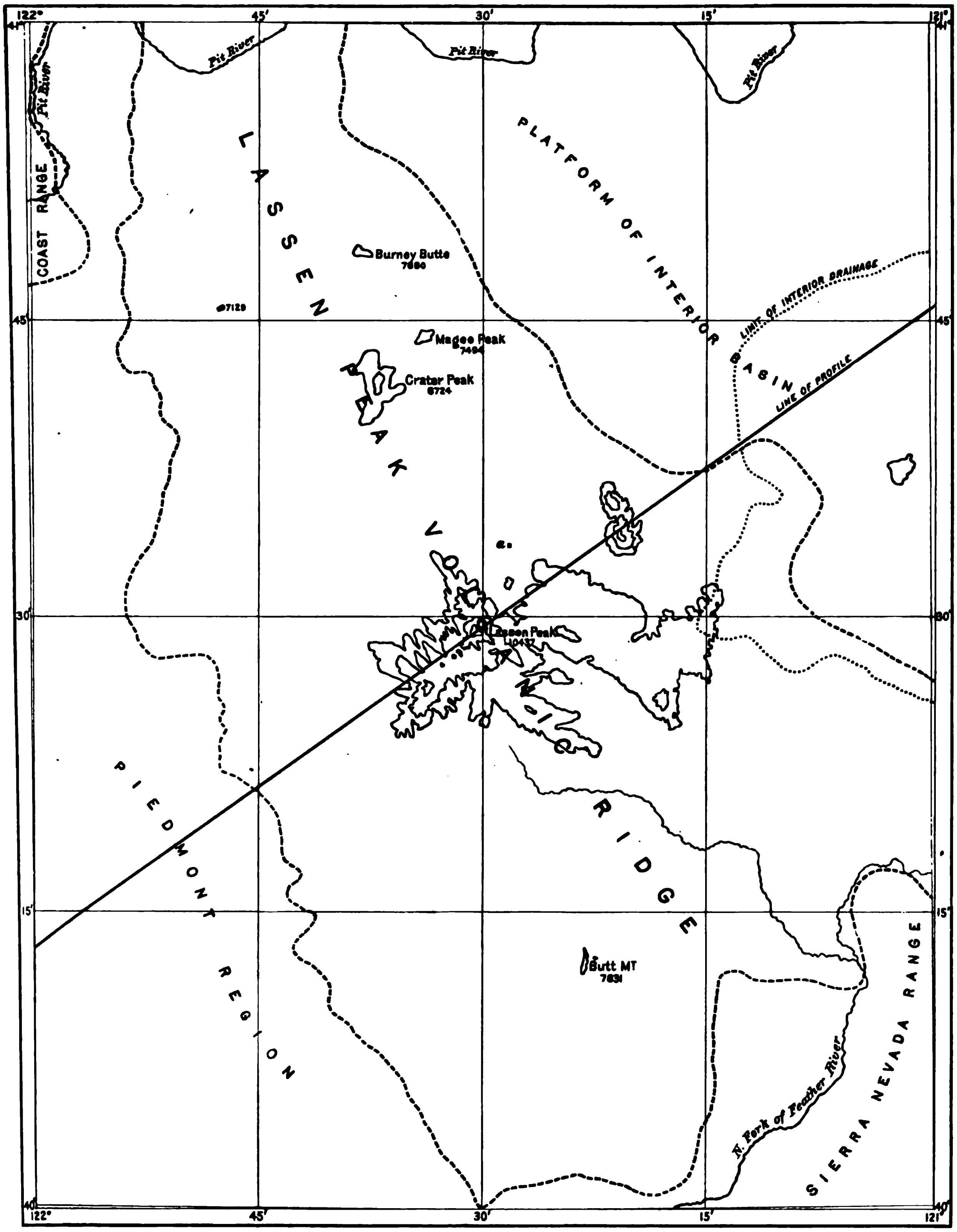


FIG. 13. Position and boundaries of the Lassen Peak district.



HYPSOGRAPHIC DIVISIONS OF LASSEN PEAK DISTRICT.

north fork of Feather River to Pit River. The coalescent lavas from a multitude of vents join the bases of the cones in such a way as to form an irregular serrated ridge entirely unlike those of the Sierra Nevada range in form, composition, structure, and origin. The view in Pl. XLVI may be seen from an elevation of 6,000 feet near Hat Creek, north of Lassen Peak, looking northwest parallel with the ridge. The whole width of the ridge is here shown from the Great Basin platform on the right across Crater Mountain, whose long gentle westward slopes reach the Sacramento Valley. To the northward the ridge becomes less prominent and narrowed by the impingement of the Great Basin platform, which is dotted over with small cones having no serial arrangement. Although it rests directly upon stratified rocks, the ridge, throughout a length of nearly seventy-five miles and a breadth of over twenty miles, is composed chiefly of accumulated lava and volcanic débris. By far the most majestic of this group of ancient volcanic piles is Lassen Peak, which, with its many prominent spurs, rises to an elevation of 10,437 feet, and bears large patches of perennial snow. The other prominent peaks of the belt, which attain an elevation of over seven thousand feet, are represented above that level in thousand-foot contours.

The Piedmont region, lying at the western foot of the volcanic ridge, is most prominently developed in the southern portion of the district, where it is a broad, even platform of stratified deposits gently inclined westward to the Sacramento Valley, from which it is sharply separated, as represented in Fig. 14, by a prominent bluff. All of the mountain streams on their way to the Sacramento cut deep cañons across the Piedmont.

The volcanic ridge of Lassen Peak appears to be a continuation of the Sierras, but in reality, as we shall see in the sequel, it is the connecting link between the Sierras and the Coast Range, and itself belongs geologically to the Cascade Range.

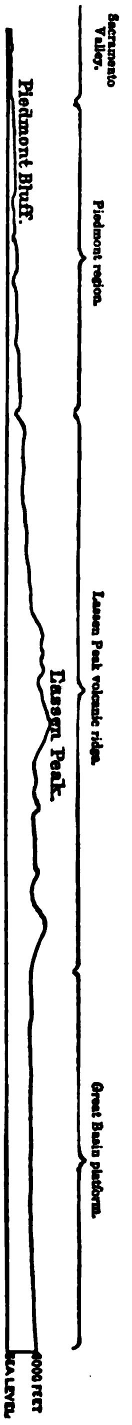


FIG. 14. Profile from the Sacramento Valley across the Piedmont of Lassen Peak into the Great Basin.

GEOLOGY.

GEOLOGIC FORMATIONS IN THE LASSEN PEAK DISTRICT.

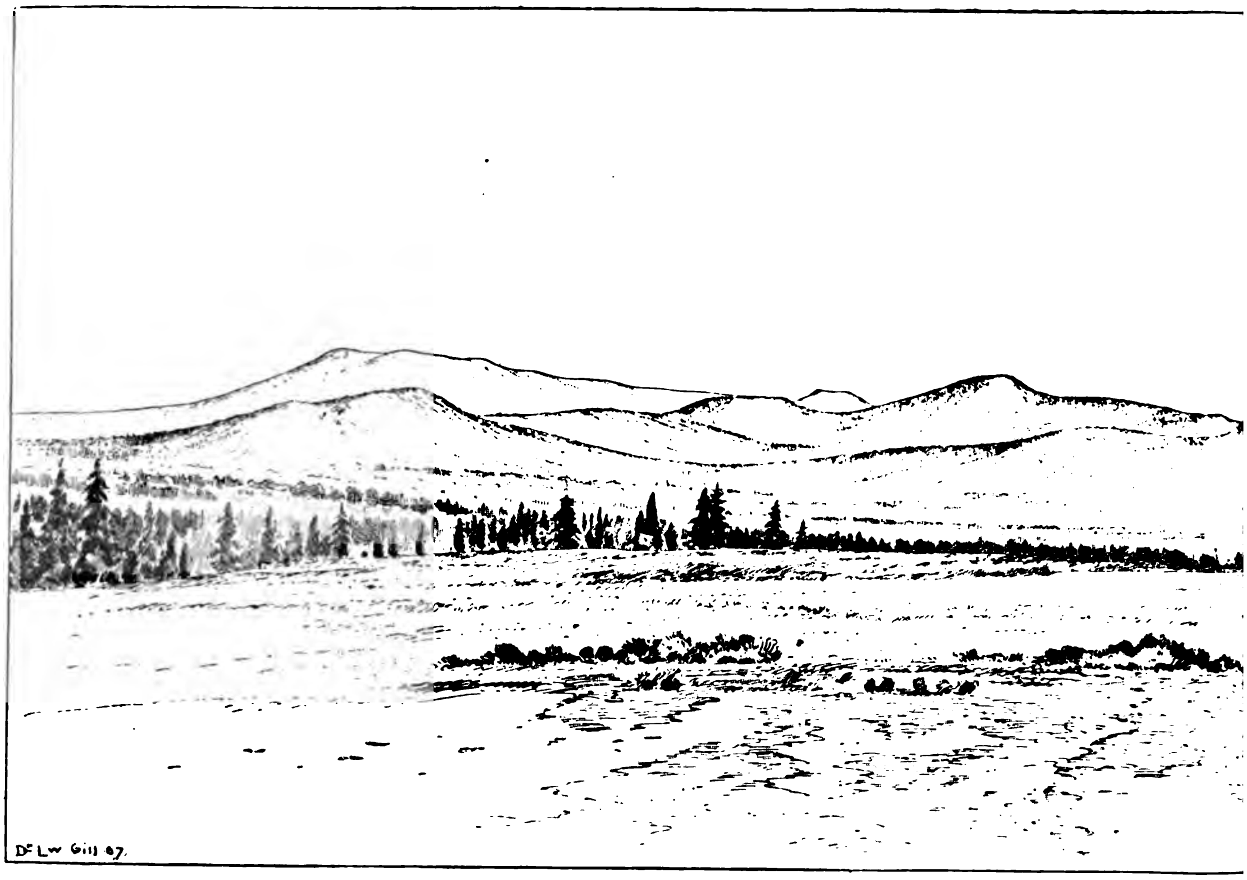
The portions of the country immediately observed by the writer while preparing the geologic map are indicated in Pl. XLVII by the routes of travel. About a thousand specimens of rocks were collected and most of them were examined microscopically. Ten formations, including stratified deposits of at least five geologic horizons and as many kinds of eruptive rocks, have been recognized in the region and delineated upon the geologic map (Pl. XLVII). Within the auriferous slate series of the district the only geologic horizon which has been determined by fossils is the Carboniferous limestone. Only the lower member (Chico beds) of the Chico-Tejon series was recognized within the district. The Tertiary consists chiefly of Miocene, but very probably embraces also the Pliocene. The eruptive rocks are rhyolite, quartz-andesite (dacite), hornblende andesite, hypersthene andesite, basalt, and quartz basalt; they will be described in another report. The sedimentary rocks will be considered in the order of age, beginning with the oldest, the auriferous slates.

AURIFEROUS SLATE SERIES.

The auriferous slate series is a very heterogeneous group of comparatively ancient sedimentary and eruptive rocks, most of which have been subjected to extensive modification, both in structure and position, since they were formed.

Distribution.—They occupy two areas at opposite extremities of the Lassen Peak district, one in the vicinity of the North Fork of Feather River and the other near Pit River. The former is at the northern terminus of the Sierra Nevada Range, where this series of gold-bearing rocks is extensively developed, and the latter is at the end of the eastern extension of the Coast Range. / These rocks do not cover as large an area in the Coast Range as in the Sierras; nevertheless they form a large portion of northwestern California and the adjacent portion of Oregon./ All of the other rocks of the district are younger than the auriferous series, and there is every reason to believe that if all of these newer rocks were swept away from the region between the North Fork of Feather River and Pit River, it would be found that they occupy a large depression in the auriferous series. This depression, transverse to the general trend of the Sierras, is a very important feature in the geographic and geologic development of that country, and I shall have frequent occasion to refer to it as forming the boundary between the Sierras and the Coast Range. From the latter portion of the Cretaceous into the Pliocene, inclusive, the depression was occupied by water, to which, for convenience, the name Lassen Strait will be applied.

Carboniferous limestone.—Among the auriferous series those formed of fine detrital matter appear to prevail, and their slaty character early suggested the name "auriferous slates" for the whole series. Interstratified with these are numerous lenticular masses of limestone containing fossils of Carboniferous age. Occasionally it is so metamorphosed as to obliterate all traces of organic remains; nevertheless their geographic distribution and relation to masses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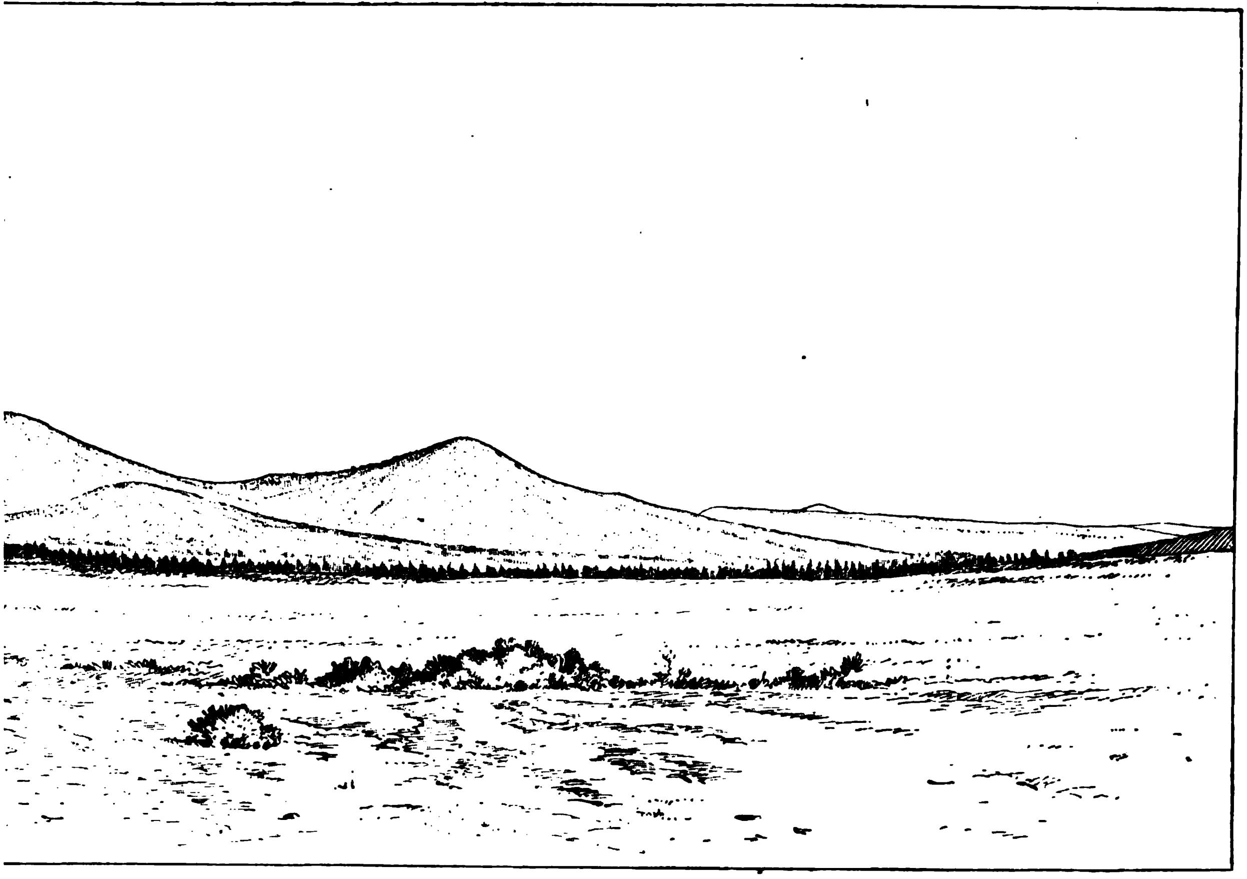
TRANSVERSE PROFILE OF LASSEN PEAK

Seen from Hat Creek, at an e



CANIC RIDGE ACROSS CRATER MOUNT.

f 6,000 feet, looking northwest.

containing fossils are such as to indicate that all are essentially of the same age.[1]

The metamorphism of the series is general, but at different points it varies greatly in intensity. In some of the finer deposits the original sedimentary character is very well preserved, but in others it is entirely obliterated by the subsequent development of a completely crystalline structure. Although finer sediments appear to predominate, those of coarser texture are by no means wholly wanting, and some of them, as we shall see presently, contain interesting fragments of older terranes.

Serpentine.—Mingled with the metamorphosed sedimentary rocks are numerous irregular masses of eruptive origin. They are chiefly of a basic character. Coarse granular plutonic rocks, such as diorites, gabbros, and peridotites, appear to be most abundant; but regular volcanic effusions are found also, together with strata composed of lapilli and volcanic sand usually in a highly altered condition.

Perhaps the most interesting rocks of the auriferous series within the Lassen Peak district are the serpentines. They appear to have a very different origin from those of the Coast Range described by Mr. G. F. Becker.[2] The serpentine which forms the prominent "Red Hill" in the junction of Indian Creek (eastern branch) and the North Fork of Feather River may be taken as a typical example of these rocks, and its genesis is exactly analogous to that of many other masses of serpentine in the northern portion of the Sierras and Coast Range. Serpentine forms a large portion of Red Hill and frequently exhibits an interesting fissile structure, splitting up into more or less distinctly lenticular, platy fragments with slickensides, as if the serpentine had been subjected to great stress, producing motion within the mass. Intimately intermingled with the well developed serpentine are both large and small irregular compact masses of olivine, which are completely permeated by a fine network of serpentine resulting from its alteration. The reticulated structure of the serpentine and its intimate association with olivine throughout the whole mass demonstrate beyond question that all the serpentine is derived from the alteration of olivine, and it is possible that the increase of volume attending the change may have given rise to the stress necessary to produce the fragments with slickensides. The rock was originally a dunite, for it was composed almost wholly of olivine with small amounts of ilmenite and a few other accessory minerals. The dunite altered chiefly to serpentine, but frequently also to needle-shaped crystals and fibrous bunches of tremolite.[1] In the latter case the weathered surface of the rock is usually colored yellowish-red by oxide of iron, and this suggested the name of the hill. Between Quincy and Spanish Ranch, as well as near Round Valley reservoir,[2] west of Greenville, in Plumas County, and at Mt. Eddy, west of Berryvale, in Siskiyou County, are great masses of serpentine containing large remnants of olivine in such a way as to clearly indicate that the original rock was a peridotite.[3]

---

[1] Within the Lassen Peak district the limestone is exposed in nearly half a dozen places. Upon the divide east of Yellow Creek, south of Humbug Valley, it contains numerous characteristic fossils, but at the exposures in the hills between Butte Valley and Prattville, and at various points along the cañon of the North Fork of Feather River, no fossils have been observed. To the northwestward, just outside of the district mapped, there are a number of exposures of the same limestone with an abundance of Carboniferous fossils. (See Bull. U. S. Geol. Survey, No. 33, 1886, pp. 10-12.)

[2] Am. Jour. Sci., 3d series, 1886, vol. 31, p. 348.

Age of the auriferous slate series.—It is well known, from the investigations of Whitney, Becker, White, and others, that the auriferous series contains both Mesozoic and Paleozoic strata, and that a large part of it belongs to the latter system. Marcou has long contended that a large portion of the strata of the Sierra Nevada Range is older than the Mesozoic, and the evidence favorable to such a view appears to be cumulative. The writer was first led to regard a very considerable portion of the series as lying below the Carboniferous limestone by an examination of the section at the head of Soda Creek, south of Mt. Shasta. There it is evident that the large mass of black shale which has a wide distribution in that vicinity lies below the Carboniferous limestone in which fossils have been found. This view was strengthened by observations at numerous other points, among which may be mentioned Hough's Mountain, between Indian Valley and American Valley, where the apparently older portion of the series is exposed by a great fault.[4] Upon the western slope of the mountain, however, the varied position of the strata renders this section less satisfactory.

A better exposure occurs in Shasta County, along Little Cow Creek, just below the point where it is crossed by the Oak Run road. The Carboniferous limestone, with traces of fossils, is distinctly underlaid by a conglomerate and black shale, both of which are evidently older than the limestone; for, as the conglomerate overlies the shale and contains its fragments, it is evident that there has been no overturning or the conglomerate would contain fragments of the limestone instead of the shale. The conglomerate contains much pyrite, and is considerably altered. Some of its pebbles are so metamorphosed as to indicate that they were derived from an older metamorphic rock, and demonstrate that below the Carboniferous limestone there is a considerable series of older stratified rocks whose age is unknown. As it becomes more and more evident that a large

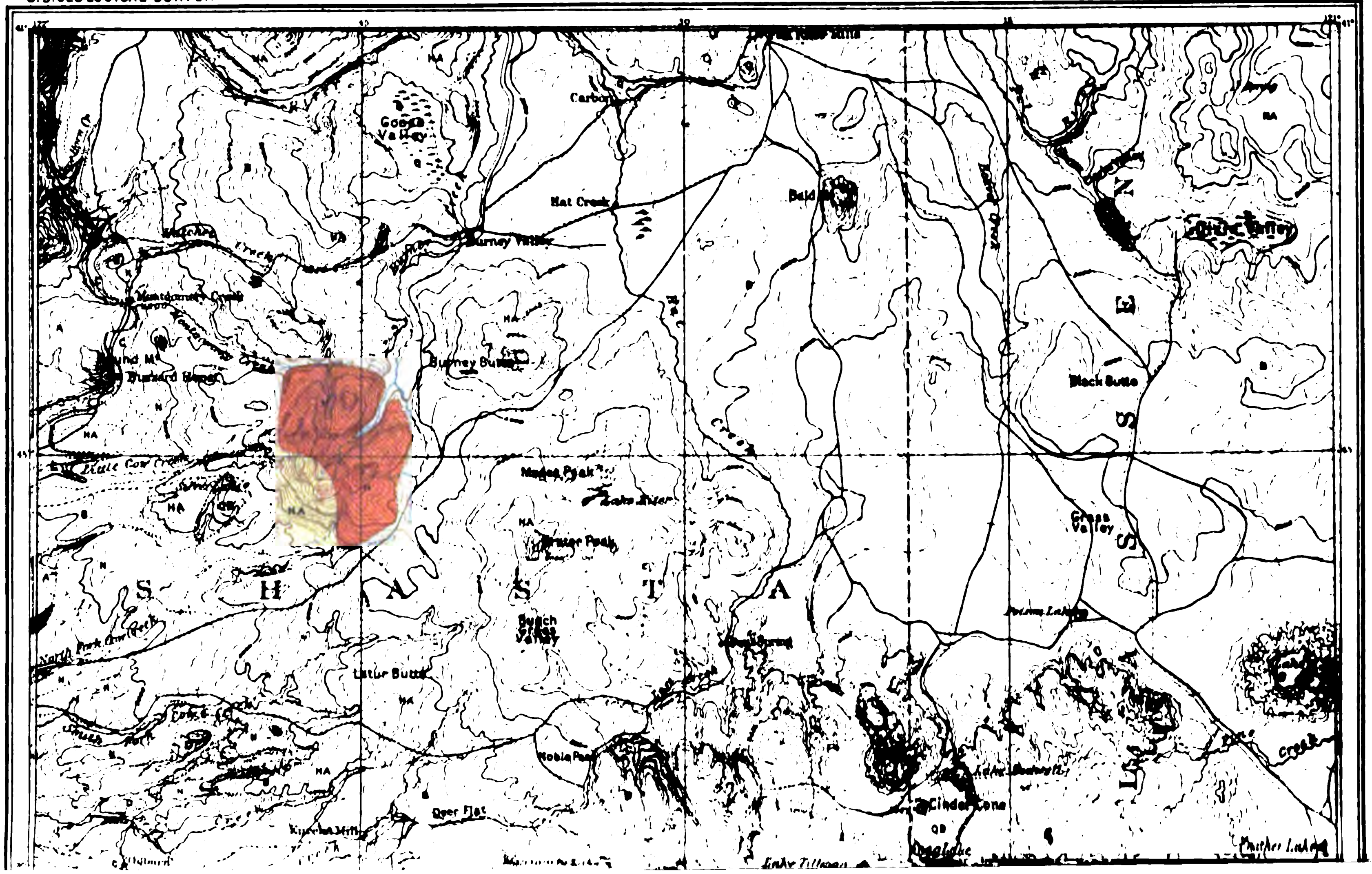
---

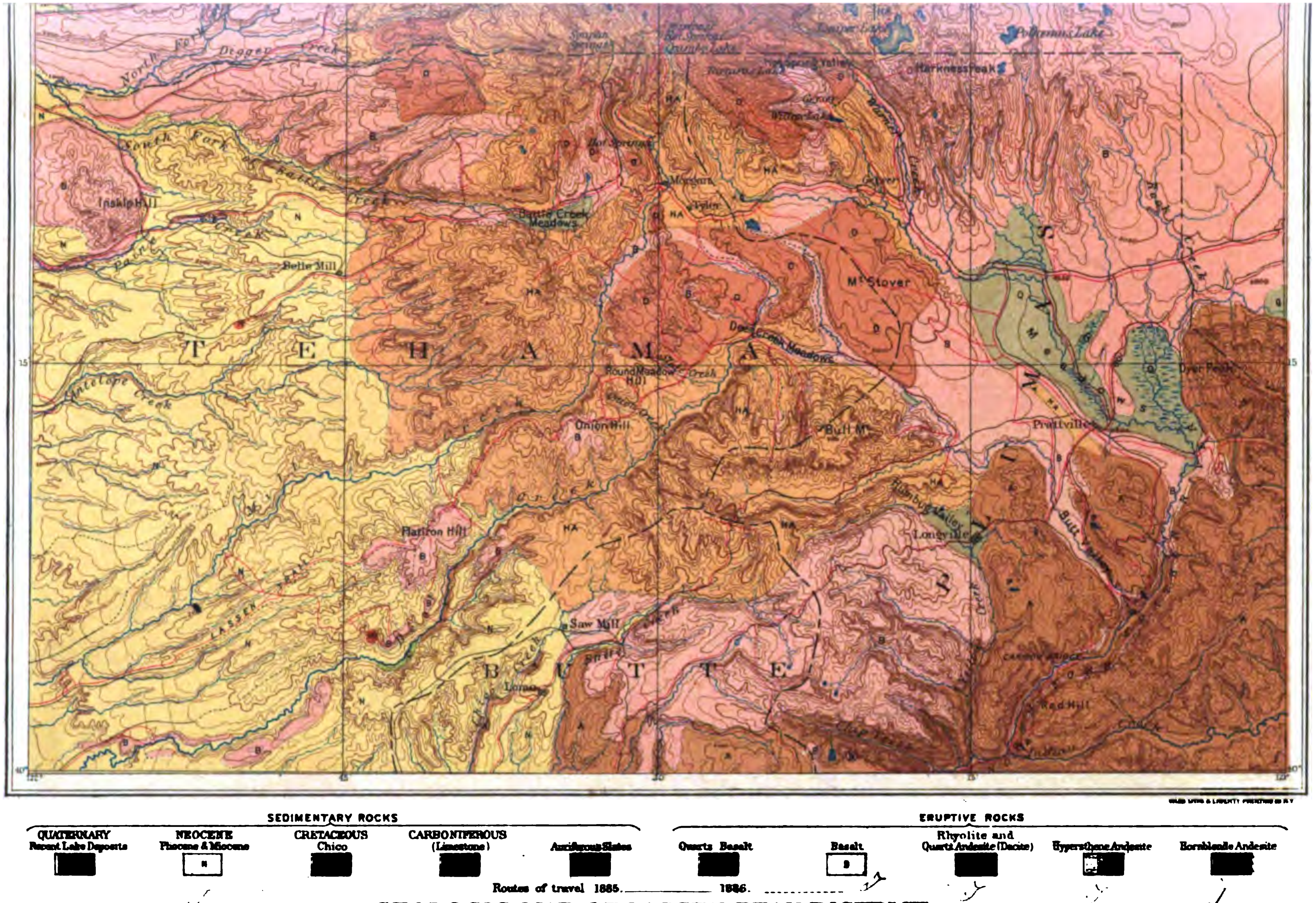
[1] Bull. U. S. Geol. Survey, No. 38, 1887, p. 24.

[2] At this locality a large number of specimens of serpentine were collected for the educational series of rocks.

[3] Dr. M. E. Wadsworth, in his Lithological Studies, p. 158, describes three serpentines from the Sierras and regards them as altered peridotites.

[4] Bull. U. S. Geol. Survey, N.. 33, 1886, pp. 13, 14.


S H A S T A
L A S S E N
Carbon
Goose Valley
Hat Creek
Burney Valley
Bald Mt
Dixie Valley
Montgomery Creek
Burney Butte
Black Butte
Little Cow Creek
Magee Peak
Crater Peak
Grass Valley
Butte Creek Valley
Latour Butte
Noble Pass
Deer Flat
Cinder Cone
Creek
HA
N
QB



GEOLOGIC MAP OF LASSEN PEAK DISTRICT.

BY J. S. DILLER.

Scale 1 400,000.

part of the auriferous slates is Mesozoic, so also the evidence is accumulating in favor of the view that another large portion is older than the limestone and possibly pre-Carboniferous.

CRETACEOUS—CHICO BEDS.

Composition.—The Chico-Tejon series is composed chiefly of soft, yellowish olive sandstone, but frequently also considerable masses of conglomerates and shales occur. The sediments of which they are composed were evidently derived directly from the auriferous slates upon which they repose unconformably. Fragments of volcanic rocks are indeed not uncommon among the pebbles of the Chico conglomerates, but they are usually much altered and quite unlike the modern lavas of the Lassen Peak district.

Distribution.—The Chico-Tejon series has a wide distribution throughout the great central valley of California, and outcrops at many places along the foothills upon both sides. The lower member of the formation reaches the very northern limit of the valley and extends eastward through the Lassen Peak district, beneath modern lavas, far into Oregon. Formerly it was completely covered by later stratified deposits, but at a number of places in the Piedmont region these have been removed and the strata of the Chico group again brought to light.

In the cañon of Chico Creek, between eleven and sixteen miles east of the village of Chico, the yellowish olive Cretaceous sandstone is well exposed for several hundred feet. It has yielded at this locality a few fossils, which were identified by Dr. C. A. White. They are noted in the list of fossils, p. 410.[1] These fossiliferous sandstones dip westerly about 6 degrees, while the inclination of the overlying stratified tufas is considerably less. As the declivity of the stream is not so great as that of the Cretaceous sandstone, they disappear beneath its bed before reaching the limit of the Piedmont region. At its eastern border the Cretaceous sandstone attains an elevation of about one thousand eight hundred feet above sea level, and rests unconformably upon the contorted auriferous slates.

Similar strata have been observed in the cañons of Deer and Mill Creeks, but no fossils were seen by the writer at either of these localities. Fossils have been reported, however, in these cañons, and also in that of Antelope Creek, by the late Professor Gans, of Red Bluff, but their exposures could not be found within the time at my disposal. At the Tuscan Springs, six miles east of Red Bluff, and just outside of the western border of the map, there is an exposure of the Cretaceous rocks which has yielded Professor Whitney an abundance of fossils.[2]

Proceeding northward, the next locality for Cretaceous fossils is in the dry bed of a small stream near the eastern base of a prominent cinder cone in Shasta County, about six miles southwest of Shingletown. The exposure is a very small one, laid bare by the removal of the superincumbent tufas. Numerous fossils are said to have been collected at an outcrop south of Darr's saw mill and at the falls in the South Fork of Bear Creek, but the limits of the exposure have not been traced.

---

[1] Most of these fossils are unlike the ones collected by Professor Whitney at the same locality. (Geol. Survey California, Geology, vol. 1, 1865, p. 209.)

[2] Ibid., p. 207.

Upon the North Fork of Bear Creek and the South Fork of Cow Creek is a large tract of Cretaceous characterized by its organic remains. These two streams are separated by a prominent ridge which is perhaps generally known in that vicinity as Bear Creek Hill. It is capped by a remarkably interesting flow of streaked lava lying upon volcanic and other sediments, which in turn are underlaid by the Cretaceous. Near the northern base of this ridge the fossiliferous sandstone dips at an unusually high angle (12°) southeasterly beneath the hill in such a way as to suggest that the hill originated in part by dislocation. At an elevation of 1,600 feet, near the western end of this ridge, in a gulch opening into the South Fork of Cow Creek, a few fossils were collected.[1] Prominent among them is *Baculites chicoensis*. At Coal Gulch, upon the North Fork of Cow Creek, traces of coal have been found and prospected unsuccessfully in the Chico group. A short distance farther north, on the South Fork of Clover Creek, the fine, shaly beds of the same formation contain a number of fossils.[2] At this point the Cretaceous is found resting directly upon the contorted and highly metamorphosed auriferous slates. In the same neighborhood, one-half a mile south of the falls in the North Fork of Clover Creek, a large number of specimens of an interesting fossil oyster were found. It occurs at an elevation of 1,300 feet and forms a veritable shell heap, filling a small depression in the metamorphic rocks by which it is completely surrounded, although within a few yards of the border of the characteristic fossiliferous Cretaceous sandstone. There can be no doubt that this fossil oyster belongs to the Chico group, and as it is new, a brief description of it by Dr. White is given below.[3]

A few miles beyond the western limit of the map, between the north fork of Cow Creek and Clover Creek, at Basin Hollow, is an interesting and very instructive exposure of the Cretaceous rocks, where over two hundred and fifty feet of them may be examined. They are composed chiefly of fine shales, but there are prominent ledges of sandstone and conglomerate also. One bed of the latter is nearly twenty feet in thickness and contains some pebbles which are at least four inches in diameter. Chico fossils[1] are found abundantly both above and below as well as within the conglomerate. The fine shaly beds during the rainy season give rise to the peculiarly adhesive and never-to-be-forgotten mud which is known throughout the West as adobe. The adobe land upon the northeastern border of the Sacramento Valley is all confined to the outcrop of the rocks of the Chico group, and a knowledge of this fact is of great service in tracing its outlines.

---

[1] Lot number 2 in the list, p. 410.

[2] Lot numbered 4, p. 410.

[3] *Ostrea* (*Alectryonia*) *Dilleri* White.—Shell sub-elliptical in marginal outline, the irregularity of which is increased by a more or less prominent posterior wing; both valves more or less convex, but the lower one more capacious than the other; muscular impression large, and situated in the postero-dorsal region. Surface marked by numerous strong radiating ribs, which give the free margin a strongly dentate character. (See Bull. U. S. Geol. Survey, No. 50, Pls. 1 and 2.)

On Little Cow Creek, where it is crossed by the Oak Run road, there is a fine exposure of fifty feet of Chico conglomerate, containing near its base numerous fossils.[2] Its unconformable contact with the auriferous slates is very well exposed. Overlying the conglomerate is a mass of fine sandstones and shales, which, according to Mr. Luppe Eiler, who has thoroughly prospected the country, occasionally contains thin seams of coal. At one locality it is said about five tons of coal were mined before the supply was exhausted, but the quality of the coal did not prove satisfactory. From Little Cow Creek the Chico group forms a belt skirting the auriferous slates northeasterly, then northerly beyond the Pit River. It is a near-shore deposit all the way, abutting directly against and resting unconformably upon the auriferous slates from which it was derived. The latter extend far northwestwardly into the Coast Range. The actual presence of the unaltered Cretaceous rocks along this belt is demonstrated by a number of fossils, including the genera *Ammonites* and *Inoceramus* found at Kosks Creek, in the great bend of Pit River.

Age of the fossils.—As already stated, a large number of fossils were collected from the series of rocks now under consideration. They were studied by Dr. C. A. White, whose list of identified forms from each locality is given in the following table. Concerning the fossils as a whole, he says that "they all belong to the Chico group, i. e., the lower or Cretaceous member of the Chico-Tejon series. None of the forms suggests the presence of the Horsetown beds below or the Tejon member of the series above."

---

[1] Lot No. 3, p. 410.

[2] Lot No. 6, p. 410.

List of identified forms.

No. 1. Cañon of Chico Creek, 15 miles east of Chico.	
Trigonia Evansana	Meek.
Venus varians	Gabb.
Fulguraria Gabbi	——.
Cinulia obliqua	Gabb.
Turritella uvasana	Con.
Baculites chicoensis	Trask.
Aporrhais falciformis	Gabb.
Ammonites Newberryanus	Meek.
Ammonites chicoensis	Trask.
Gasteropod, sp. nov.	

No. 2. Gulch on south side of South Fork of Cow Creek; elevation 1,600 feet.	
Modiola cylindrica	Gabb.(?)
Nucula truncata	Gabb.
Baculites chicoensis	Trask.

No. 3. West end of Basin Hollow, near Blodget's.	
Trigonia Evansana	Meek.
Axinæa Veatchi	Gabb.
Venus varians	Gabb.
Axinæa sagittata	Gabb.
Tellina undulifera	Gabb.
Dentalium Cooperi	Gabb.
Cinulia obliqua	Gabb.
Gasteropod, sp. nov.	

No. 4. South Fork of Clover Creek; elevation about 1,400 feet.	
Axinæa Veatchi	Gabb.
Tellina Hoffmaniana	Gabb.
Pugnellus hamulus	Gabb.
Fulguraria Gabbi	White.
Cinulia obliqua	Gabb.

No. 5. One-half mile south of Clover Creek Falls.	
Ostrea Dilleri	White.

No. 6. Little Cow Creek, one-fourth mile below Oak Run Road Crossing.	
Axinæa sagittata	Gabb.
Tellina Hoffmaniana	Gabb.
Tellina undulifera	Gabb.
Tellina Ashburneri	Gabb.
Meretrix nitida	Gabb.
Axinæa Veatchi	Gabb.
Gyrodes Conradiana	Gabb.
Lunatia unciformis	Gabb.
Nucula truncata	Gabb.
Gasteropod, sp. nov.	
Gasteropod, sp. nov., like in No. 3.	

No. 7. Little Cow Creek, 2 miles east of Woodman's, 20 miles east of Redding.	
Axinæa Veatchi	Gabb.
Pugnellus manubriatus	Gabb.
Actæonella oviformis	Gabb.
Gyrodes Conradiana	Gabb.

No. 8. Little Cow Creek, near Joseph Yanks, 16 miles east of Redding.	
Axinæa Veatchi	Gabb.
Cucullæa Mathewsoni	Gabb.
Ostrea	——.
Trigonia Evansana	Meek.
Actæonina pupoides	Gabb.
Anchura monilifera	Gabb.
Gasteropod, sp. nov.	
Gasteropod, sp. nov.	

Species common to several localities:

	Lots.
Axinæa Veatchi	3, 4, 6, 7, 8
Trigonia Evansana	1, 3, 8
Cinulia obliqua	1, 3, 4
Axinæa sagittata	3, 6
Tellina Hoffmaniana	4, 6
Tellina undifera	3, 6
Baculites chicoensis	1, 2
Venus varians	1, 3
Gyrodes Conradiana	6, 7

Upper and lower limits.—The Chico rocks are chiefly soft, friable, yellowish-olive sandstones, which continue to occupy almost the same position as that in which they were originally laid down, excepting perhaps the exposures at Tuscan Springs, and at the northern base of Bear Creek Hill. Since their deposition, although they have been subjected to very moderate differential uplifting, they have not experienced the slightest metamorphic changes, and remain entirely unaltered. On the other hand, the auriferous slates upon which they have been found at a number of places to discordantly repose were greatly metamorphosed before the beginning of the Chico epoch. The interval between the time when the auriferous slates assumed their present structure and position and the beginning of the Chico epoch may have been a very long one, but it has no representative among the formations of the Lassen Peak district. The lower limit of the Chico group is clearly defined, but the upper limit in the same district is not easily determined. Messrs. White and Becker[1] have shown that in the southern portion of the great valley of California the Chico-Tejon series is very extensively developed, attaining the enormous thickness of 10,000 feet. Its maximum thickness in the middle of the northern portion of the Sacramento Valley is as yet unknown, but the greatest observed is only a few hundred feet. It must be remembered, however, that the only portion of the series now exposed is its edge, much attenuated upon the borders of the great depression (Sacramento Valley) which it fills. The presence of the lower member of the Chico-Tejon series in the Lassen Peak district is a matter beyond question, and the absence of the upper member can hardly be doubted. This state of affairs brings the Miocene into the place of the Tejon, a condition which was not fully recognized until the fossils were determined. This subject will be adverted to again when considering the Miocene.

GEOGRAPHY OF THE DISTRICT DURING THE CHICO EPOCH.

The geography of northern California during the Chico epoch is outlined upon the accompanying sketch (Fig. 15). Attention has already been called to the fact that the Chico beds at the northeastern extremity of the Sacramento Valley, in the vicinity of Pit River, are near-shore deposits. The shore line can be traced from this point westward and southwestward along that part of the Coast Range which bounds the northern extremity of the Sacramento Valley. To the northward the littoral deposits appear along the western border of Shasta Valley, in the vicinity of Yreka, and may be traced directly into Oregon. It is evident that these shore deposits were derived from an insular area of the auriferous slates which now form the prominent mountains of northwestern California and the adjacent portion of Oregon.

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[1] Bull. U. S. Geol. Survey, Nos. 15, 19, 1885.

Near Pence's ranch, twelve miles north of Oroville, there are interesting exposures of Chico rocks which rest directly and discordantly upon the auriferous slates. They rise in the foothills of the Sierras to an elevation of about one thousand feet above sea level, but do not reach Cherokee flat. At that place strata younger than the Cretaceous rocks of the neighborhood repose immediately upon the metamorphics. In the cañon of Chico Creek, where the Chico beds were next examined, they rise upon the western slopes of the auriferous series to an elevation of about eighteen hundred feet, and, as at Pence's, dip slightly to the westward away from the old shore line along the western border of the sierra platform. From this point northerly the littoral deposits are covered up by the extensive effusions of lava.

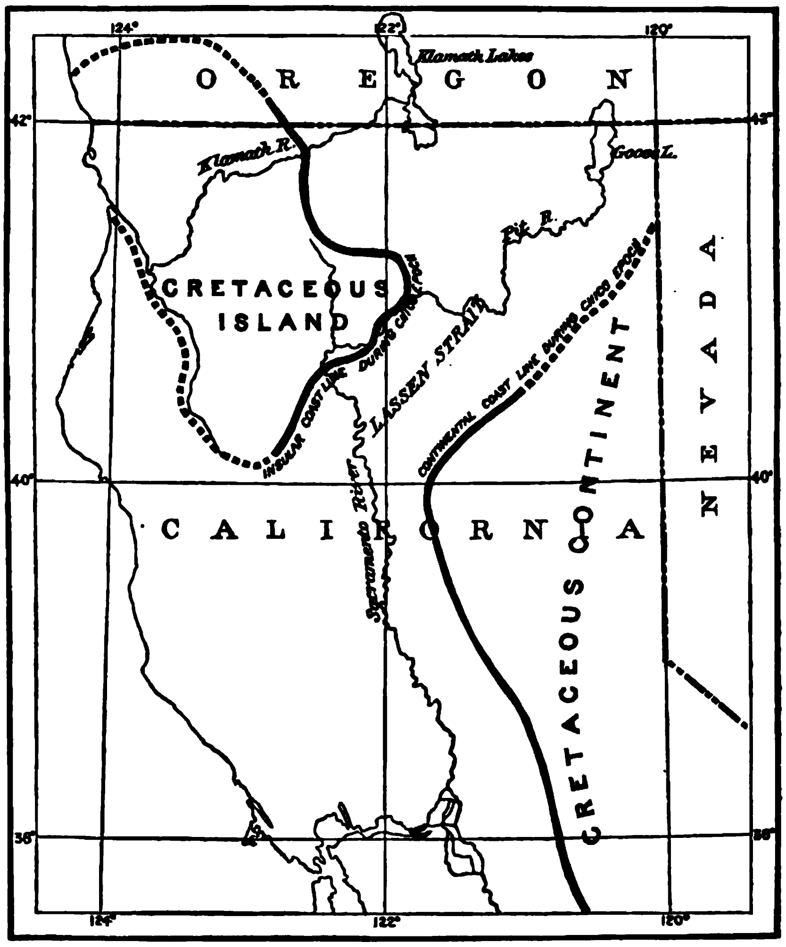

FIG. 15. Geography of Northern California during the Chico epoch.

from the volcanoes in the Lassen Peak district, but there can be no doubt that the ancient coast extended northeasterly around the northern end of what is now the Sierra Nevada range towards the headwaters of Pit River, and that during the Chico epoch the Lassen Peak district lay almost wholly within Lassen Strait, which separated the island of northwestern California from the continental land to which the Sierra country belonged.

MIOCENE.

Composition of the Miocene strata.—The Miocene formation embraces sandstones with finer sediments and considerable conglomerate. The detritus of which they were formed was, like that of the Chico group, derived directly from the auriferous slates. In this respect they are strongly contrasted with that of the succeeding deposits, which are composed almost exclusively of volcanic material.

Distribution and relations.—Within the Lassen Peak district there is a large area of Miocene deposits lying in the Piedmont region. One of the best exposures is on Little Cow Creek, in Shasta County, at an elevation of about twenty-nine hundred feet. At this point the creek leaves a bold, rugged cañon, cut deep into the light colored sandstone and pebbly beds, and enters upon the irregular, hummocky area that leads to the adobe land on the Chico rocks farther down stream. At the mouth of the cañon, in a fine shaly bed intercalated between the sandstone, a number of fossil leaves were found, which have been identified by Prof. Leo Lesquereux and the results are given in the accompanying list (page 420). With the fossil leaves was found a fresh-water mussel, identified by Dr. R. E. C. Stearns as *Anodonta Nuttalliana.* The horizontal strata conformably overlying the fossils are chiefly coarse sandstones occasionally containing fine gravel. They are somewhat lighter colored than the members of the Chico group and a thickness of over five hundred feet of them is exposed along the sides of the cañon. The whole series is capped by a lava flow. A few miles to the northeastward, about the head of Montgomery Creek, where the upper portion of the series is exposed, it may be seen that the sandstones pass upward into conglomerates and the volcanic material becomes more abundant near the summit of the series. At this point the strata dip slightly to the eastward away from the shore line and beneath the lavas of the volcanic ridge. A few miles down Little Cow Creek from where the fossil leaves were found, near the Oak Run road bridge, the marine shells of the Chico group were collected, and the difference in elevation of the two exposures, taken in connection with the position of the strata, suggests that there may be a great thickness of finer sandstones and shales between them. The contact between the Chico beds and the Tertiary deposits has not been observed, but their relative positions at adjacent exposures indicate that they are slightly unconformable. The Chico beds extend about a mile up Little Cow Creek from the bridge and dip to the westward. The Tertiary deposits of the hills near by to the northward overlap the Cretaceous and dip gently in the opposite direction, so that there can be scarcely a doubt concerning the discordance of the two formations.

The Miocene formation in the Lassen Peak district, as already remarked, is composed of sandstones and shales below, and conglomerate above. The lower member is least liable to exposure, but its presence is generally indicated by a peculiar, hummocky topography quite unlike that of any other strata in the district. The small hillocks are not always round; they vary in form like the little drumlins of a glacial field and have between them small basins which in the rainy season contain lakes. That such a topographic feature is not the consequence of ordinary erosion has been remarked by many of the mountaineers, who attribute them to land-slides, and this view is supported by the fact that the hummocks are best developed where the general slope has considerable declivity. The finest examples within the district have been seen in the neighborhood of Little Cow Creek, but they were observed also near Lone Rock, south of Light Cañon, in Plumas County, as well as northeast of Coppervale, near the head of Mountain Meadows, where the same formation occurs.

The prominent ridge between Bear Creek and the South Fork of Cow Creek affords an unusually interesting exposure of the upper portion of the Miocene. At the very base of the hill, in the beds of both streams, Chico fossils have been found, so that the hill undoubtedly rests upon the Cretaceous. Above the fossiliferous beds is a considerable thickness of sandstone capped by a heavy layer of conglomerate, and overlying this is usually found a remarkable flow of tufaceous rhyolitic lava. The conglomerate at this point shows apparently a greater development than anywhere else within the district. It has been mined for gold, but without marked success. One of the miners of the region says that it contains enough fine gold to pay from 50 cents to $1 a day. The gravel has only a local development, for it is limited to the slopes of Bear Creek Hill, with a short extension eastward up the North Fork of Bear Creek, where it is mined. This linear extension east and west down the general slope and transverse to the usual strike of the Tertiary strata indicates that the gravel deposit is an old stream bed. Additional evidence in favor of the same view is to be found in the fact that in the immediate vicinity the conglomerate is absent and the overlying tufas (Pliocene) rest directly upon an eroded surface of the sandstone below.

That much of the conglomerate has been washed away is evident from the traces it has left behind. Between the Tamarack road and the North Fork of Cow Creek there is a prominent ridge extending southwesterly from the group of prominent hills about the headwaters of Burney Creek. The western terminus of this ridge is rather abrupt, and it is composed chiefly of hypersthene-andesite overlaid by basalt. High up on its slopes, lying on the andesite, are frequently found well rounded pebbles, often grouped in great abundance, but generally rather sparingly scattered over the surface. They proclaim the former presence of the Miocene conglomerate. ?Upon the northern side of this ridge, near the head of the cañon of the North Fork of Cow Creek, at an elevation of 3,000 feet, the conglomerate occurs in place resting upon the Miocene sandstone, which has an extensive development further westward on the divide between the North Fork of Cow Creek and Clover Creek. The pebbles on the ridge above referred to reach an elevation of 3,200 feet. Near the head of Oak Run, on the road to Silver Lake, pebbles of metamorphic rocks are scattered quite abundantly over the fresh andesitic lava up to an elevation of nearly four thousand feet. The great elevation at which these pebbles now occur may be due in part perhaps to upheaval since their deposition. These pebbles are almost wholly of quartz and other metamorphic rocks, very unlike the lavas upon which they rest. In places they appear also to overlie tufa, and it is difficult to satisfactorily explain the presence of so small a number of volcanic fragments in a conglomerate so intimately associated with the lavas.

Pebbles on andesite

How could Miocene [illegible]

Superficial [illegible]

South of Bear Creek the Miocene is not so extensively developed nor so well exposed. On the South Fork of Shingle Creek, near the prominent crater about sixteen miles directly east from Anderson, lying between the fossiliferous Cretaceous and the tufa there is but a thin body of Miocene strata. A better exposure is obtained on Ash Creek, six miles east of Ball's Ferry.

Notwithstanding the thick deposit of tufa (Pliocene) in the Piedmont region, the deep cañons cut across it by the mountain streams occasionally reach the Miocene beds upon which the tufa rests. Along Mill Creek, about twenty miles east of Tehama, where the sandstone is exposed, its upper surface was irregularly eroded before the deposition of the tufa, just as in the case already noted along the South Fork of Cow Creek.

In the cañon of Deer Creek, at an elevation of about two thousand two hundred and fifty feet, there is a remnant of an ancient stream bed of auriferous gravel, which is apparently equivalent to the Miocene conglomerate and has been extensively mined. The gravel is about thirty feet thick and is composed of well rounded pebbles less than four inches in diameter. The pebbles are chiefly of metamorphic rocks, but fragments of lava are also common. The whole is overlaid by tufa as represented in Fig. 16.

Thus far our attention has been given to the Miocene deposits of the Piedmont region within the western portion of the Lassen

Peak district. We will now turn our attention to similar deposits found outside of the district southeast of Lassen Peak, about the Mountain Meadows and in the neighborhood of Light Cañon. The formation is apparently continuous from one locality to the other, but the best exposures of it are at the place last mentioned. The northern extremity of Light Cañon opens into a basin-shaped region lying between Lone Rock and the northeastern terminus of Moonlight. This basin was once filled with Miocene lacustrine deposits, of which only a small portion now remains. The sandstone at its base has a thickness of over five hundred feet, and its horizontal beds are well exposed upon the hillsides west of Light Cañon, where they form prominent bluffs. To the east of Light Creek, near Lone Rock, the sandstone is soft and incoherent, so that instead of forming cliffs it gives rise to the peculiar hummocky topography to which reference has already been made. Fossils have not been found in the sandstone of this basin, but at the northern end of Mountain Meadows, near the main road one mile southwest of the point where it crosses the summit towards Susanville, the few fossil leaves which are noted in the list (page 420) have been found. In both localities and at a number of intermediate points connecting the two principal outcrops the sandstone is overlaid by a heavy layer of gravel, which is occasionally cemented so as to form a very firm conglomerate. This gravel has attracted much attention, not only on account of its position, but more particularly because it is auriferous. At both ends of the Mountain Meadows it has been mined, and the work still continues during the rainy season, when sufficient water can be obtained. Within the drainage area of Light Creek the operations have been more extensive and perhaps also more profitable. Considerable money has been spent searching within the lacustrine deposits for old stream beds, which will in all probability never be found. The conglomerate or loose gravel, which has either never been cemented or else resulted from the disintegration of the conglomerate, is widespread, and reaches an elevation of nearly seven thousand feet on the very crest of the eastern escarpment of the Sierras, near Thompson Peak. The lower portion of the gravel is composed almost wholly of pebbles of metamorphic rocks. They are very smooth and well

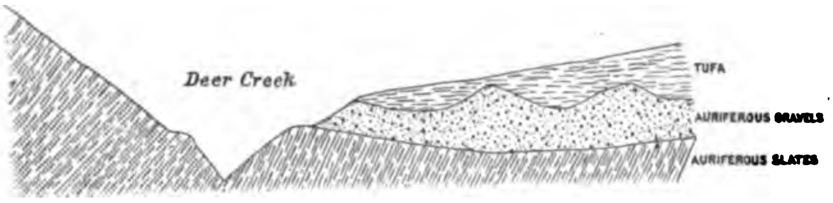

FIG. 16. Section of auriferous gravel at Deer Creek mines.

rounded, frequently showing the ellipsoidal form characteristic of beach action.[1] In the upper portion the pebbles are larger and those of modern lavas more abundant. Excellent exposures of the upper portion of the gravel occur along the crest a few miles southeast of Diamond Peak, where it forms a prominent, smooth ridge, rising at least one hundred and fifty feet above its base. The pebbles are of all sorts. Those of quartz and of the auriferous slates and granite are generally smaller and much less abundant than those of andesitic lava, which are not infrequently two feet in diameter. A short distance north of the road, where it crosses the summit between Light Cañon and Susanville, at the head of a stream which flows into Susan Creek, the gravel is cemented into a firm conglomerate. It is about three hundred and fifty feet thick and dips slightly to the eastward. High up on the mountain side it rests directly upon the granitic rocks, but at lower levels on both sides of the mountain it is underlaid by the sandstone. Within the conglomerate are occasional thin beds and lenticular masses of shale, which are much indurated, as we shall see further on, by the orographic movements which gave birth to the Sierras. In one of these shales, less than twenty inches in thickness and of limited extent horizontally, numerous fossil leaves have been found.[2]

The fossils were determined by Prof. Leo Lesquereux, whose results will be found in the appended list (p. 420).

While examining the general structure of the Sierras in the vicinity of Indian and American Valleys I had an opportunity to visit the summit of Spanish Peak and collected some fossils from the auriferous gravels of the Monte Christo mine.[1] The gravel mined at this place is doubtless closely related to that at Lot's Diggings, about twelve miles to the northwest and high up on the opposite side of the cañon of the North Fork of Feather River. The gravel is very smooth and round, just like that of the lacustrine deposits east of Indian Valley, but, unlike the latter, it appears to belong to a stream bed. The form of the deposit appears to be linear and confined to a definite channel, which is from one hundred to six hundred feet in width at the surface and about four hundred feet deep. The upper portion of the deposit is chiefly gravel and the lower part distinctly stratified, fine, argillaceous sand or clay (pipe clay), which at some places rests directly upon the granite, at others is underlaid by conglomerate. The fossils were found at a distance of nearly three thousand feet from the mouth of the tunnel and approximately two hundred and seventy-five feet below the surface, in the clayey strata. They occur in great numbers and can be obtained in an excellent state of preservation, but the bed containing them is so soft as to readily disintegrate. Besides the leaves noted in the list of determinations by Professor Lesquereux (p. 420), a fossil fresh-water fish[2] was found in the same bed.[3] The form and structure of the deposit indicates that it is fluviatile, like the great mass of the auriferous gravels on the western slope of the Sierras described by Prof. J. D. Whitney[4] and others; but what relation it holds to the lacustrine deposits to the northeastward has not yet been determined. The character of the pebbles is such as to suggest that they may have been derived from the lacustrine deposits, but there are other considerations which suggest for them a greater antiquity. At Cherokee, for example, in the mine of the Spring Valley Hydraulic Gold Company, the auriferous gravels are overlaid by several hundred feet of fine conglomerate and soft sandstone, which have furnished a few leaf impressions[1] to indicate that the deposits belong to the Miocene fresh water lacustrine beds so extensively developed in the Piedmont region. It is evident that the auriferous gravels underlying these deposits belong to an early portion of the Miocene or to the Eocene.

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[1] Normal wave action on a beach rolls the pebbles back and forth about the same axis and tends to produce out of cubical blocks of homogeneous stone ellipsoidal pebbles. As a rule the pebbles of a beach are not ellipsoidal, but this is due to the fact that the direction of wave motion is inclined to the coast and to irregularity of the initial form and want of homogeneity in the material. Rocks frequently split in one direction much more readily than in any other, and thus give rise to flat fragments. Their flatness is increased by beach action, because they do not roll but slide back and forth.

[2] On account of the importance and scarcity of fossils in that region their position should be more definitely described. They occur in Lassen County, about three-fourths of a mile north of the point where the Light Cañon and Susanville road crosses the summit. The surest way to reach the exposure is to start from the first small bridge, one-fourth of a mile below the summit on the Susanville side, and go up the gulch almost directly west for a few hundred yards to the summit of a partially bare ridge. Cliffs of conglomerate appear on the left (south side) as the summit is approached. The ridge or rather spur extends northerly and upon its sides soon appear two deep, precipitous, rocky gulches which unite about a quarter of a mile below. More than half way down the spur on its northwesterly slope, in an open space about fifty feet above the bottom of the gulch, the very limited exposure may be found. My attention was called to this interesting locality by Mr. W. C. Kingsbury, of San José, Cal., who discovered these fossils while prospecting for gold thirteen years ago.

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[1] I am greatly indebted to Mr. Malcolm Matheson, superintendent of the mines, not only for much valuable information, but also for guiding me through the extensive series of underground passages in the mine and rendering efficient service in the collection of fossils.

[2] It was examined by Prof. W. H. Dall, who reports that "the fish appears to have had no scales; the teeth were so small, if any, that they have left no traces on the impression. The dorsal and ventral fins are evidently more or less imperfect, and the tail is altogether wanting. The form of the anterior extremity of the pectoral fin, the lateral tine, and the remaining indications of the posterior fins agree fairly well with those of *uranidea*, a genus of small fresh-water cottoids which are particularly abundant at the present day in the streams of California. At all events the opinion may be expressed with some confidence that the fish was not marine and that it was related to *uranidea*."

[3] The fossil fish was found several years ago by Mr. J. G. Phelps, who has kindly donated it to the National Museum of Washington, D. C.

[4] The auriferous gravels of the Sierra Nevada of California: Memoirs of the Museum of Comparative Zoölogy at Harvard College, vol. 6; No. 1, 1883.

Fossils found in the Miocene strata.—The following tabular view gives a list of all the plant remains found in the formation just described. The figures indicate the number of specimens of each species found. All of the determinations were made by Prof. Leo Lesquereux, who has furnished the following statements concerning their geological relations:

"*Juglans Bilinica* is found along Little Cow Creek and upon Spanish Peak, while *Phragmites Oeningensis* occurs at both of the other localities. The most abundant form, *Persea Dilleri,* is related to the living species *Persea Carolinensis,* variety *palustris,* of our south Atlantic border, and occurs both along Little Cow Creek and near the summit north of Light Cañon.

"Two species, *Magnolia Hilgardiana* and *Quercus Moorei,* are identified in the Eocene of the Mississippi; and two others, *Aralia Lasseniana* and *Oreodaphne litsœæformis,* are related to the Eocene (Sézanne and Gelinden) of France and Belgium.

"Seven species are identified in the Miocene of North America, viz: *Platanus dissecta, Laurus Californica, Cornus hyperborea, Pterospermites spectabilis, Quercus Olafseni, Laurus socialis, Juglans rugosa.*

"Five species are identified in the Miocene of Europe: *Myrica Ungeri, Juglans Bilinica, Phragmites Oeningensis, Oreodaphne Heeri,* and *Cinnamomum Scheuchzeri.*

"Three species have been identified with those of the auriferous gravels of California, viz: *Ficus microphylla, Magnolia Californica,* and *Platanus dissecta.* These three, with *Cornus Kelloggi* as closely related to *Cornus hyperborea* and to the living *Cornus Nuttalli* of California, represent the recent forms of plants described above. The relation is therefore evidently to the Miocene."

Prof. Lester F. Ward, who not only saw the fossils but also examined the list of species, determined by Professor Lesquereux, expressed the opinion that the strata from which they were taken, as well as the auriferous gravels, the upper portion of the John Day group, with those at Corral Hollow and perhaps the Bellingham Bay beds, all belong to the same series, and he agrees with Professor Lesquereux that they are Miocene, most likely Upper Miocene.

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[1] See Prof. L. F. Ward's report in Bull. U. S. Geol. Survey, No. 33, 1886, p. 16.

List of fossil leaves determined by Prof. Leo Lesquereux.

Species.	Little Cow Creek, Shasta County, Cal.; elevation, 2,900 feet.	Northeastern corner of Mountain Meadows by main road, 1 mile southwest of where it crosses summit towards Susanville, Lassen Co., Cal.; elevation, 5,000 feet.	Three-quarters of a mile north of where Light Cañon and Susanville roads cross the summit, Lassen Co., Cal.; elevation, 6,000 feet.[1]	Monte Christo mine, near summit of Spanish Peak, Plumas County, Cal.; elevation, 6,850 feet.
Acer Bendirei Lx				4
Alnus Kefersteini Al. Br	1			
Alnus nostratum ? Heer			1	
Aralia Lasseniana, sp. nov., Lx			1	
Asplenium Wegmanni ?			2	
Cinnamomum Scheuchzeri or polymorphum, Al. Br		1		
Cornus hyperborea ? Heer			1	
Ephedrites Sotzkianus ? Schp			1	
Ficus appendiculata ? Heer			1	
Ficus microphylla Lx	1			
Ficus Shastensis, sp. nov. Lx., related to F. scabriuscula Heer	3			
Juglans Bilinica Ung	2			1
Juglans rugosa Lx			1	
Laurus Californica Lx				1
Laurus socialis Lx			3	
Leguminosites ? species			1	
Magnolia Californica Lx			2	
Magnolia Hilgardiana Lx			1	
Magnolia Inglefieldi Heer			10	
Myrica Ungeri Heer				1
Oreodaphne litseæformis, sp. nov., Lx			1	
Oreodaphne Heeri			1	
Persea Dilleri, sp. nov., Lx., related to P. Caroliniana var. palustris Chap.	9		1	
Phragmites Oeningensis Al. Br		3	2	
Platanus dissecta Lx				3
Pterospermites spectabilis, Heer				1
Quercus Moorei Lx			4	
Quercus Olafseni ? Heer			1	
Rhus ? species.	3			

Hypsographic and climatic conditions during the Miocene.—During the Miocene the northern portion of the Sacramento Valley was occupied by an extensive fresh-water lake, which stretched far to the northeastward through Lassen Strait, that marks the limit between the northern terminus of the Sierras and the Coast Range and is now occupied by the volcanic ridge of Lassen Peak. A similar body of water existed northeast of Indian Valley, in the country now occupied by the very crest of the Sierras, northwest of Honey Lake, at an elevation of nearly seven thousand feet. From the fact that the lacustrine deposits on both sides of Lassen Peak pass beneath its lavas, it is believed that they are continuous and were all laid down in the same lake, which at that time covered a large portion of what is now the northern end of the Sierras and extended from the Sacramento Valley far into Oregon. Mr. Clarence King[1] has called attention to the wide distribution of Miocene lacustrine deposits in that region, extending from beyond the Columbia River south, through Oregon into Nevada and California, and it may now be added that they pass through the gap separating the north end of the Sierras from the Coast Range into the northern portion of the Sacramento Valley. To the large body of fresh water in which these sediments were found King gave the name Piute Lake. The Piute Lake deposits reach much farther up on the flanks of the Sierras than the littoral deposits of the Chico epoch, indicating clearly that between the close of the Chico epoch and the beginning of the Miocene there was a change in the relative elevation of the Sacramento Valley and the Sierra region. This change was effected by the elevation of at least part of the region of the Coast Range, and apparently also of the Cascade Range, so that the oceanic waters were excluded and the formation of Piute Lake was rendered possible. That this elevation occurred at the close of the Cretaceous is rendered altogether probable by the fact that the Tejon group has not yet been recognized within the Piute Lake region. Perhaps we may yet find in the earlier deposits of that lake the fresh-water equivalents of the Tejon group of western Oregon and southern California.

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[1] In Proc. U. S. Nat. Museum, 1888, p. 28, the age of the fossils from this locality is stated to be Eocene (Laramie).

The distribution of the lacustrine deposits in the Mountain Meadows region can not be well illustrated until the cartographic work of that district has been completed. Their relations, however, appear to fully justify the statement that at the time they were deposited the country to the eastward was higher than the region now occupied by the Sierras, at least in the latitude of Diamond Peak. Furthermore, if these deposits were, as we suppose, all laid down in the same lake, it is evident that during the Miocene the sediments which now form the eastern crest of the Sierras near Diamond Peak must have been on about the same level with those of the Sacramento Valley.

In answer to my question concerning the climatic condition of that region during the Miocene, as indicated by its flora, Professor Lesquereux states that "by the presence of a large number of *Laurineæ* the flora becomes related in its general characters to that of a region analogous in atmospheric circumstances to Florida." With this view Prof. Lester F. Ward also fully agrees, and it is in complete harmony with the inference drawn from structural relations, viz, that during the Miocene that country was a broad platform, with gentle relief, and but moderately elevated above the sea; or, in other words, the surface of the region was but little above its base level of erosion.

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[1] U. S. Geol. Exploration of the 40th Parallel, vol. 1, 1878, pp. 451–454.

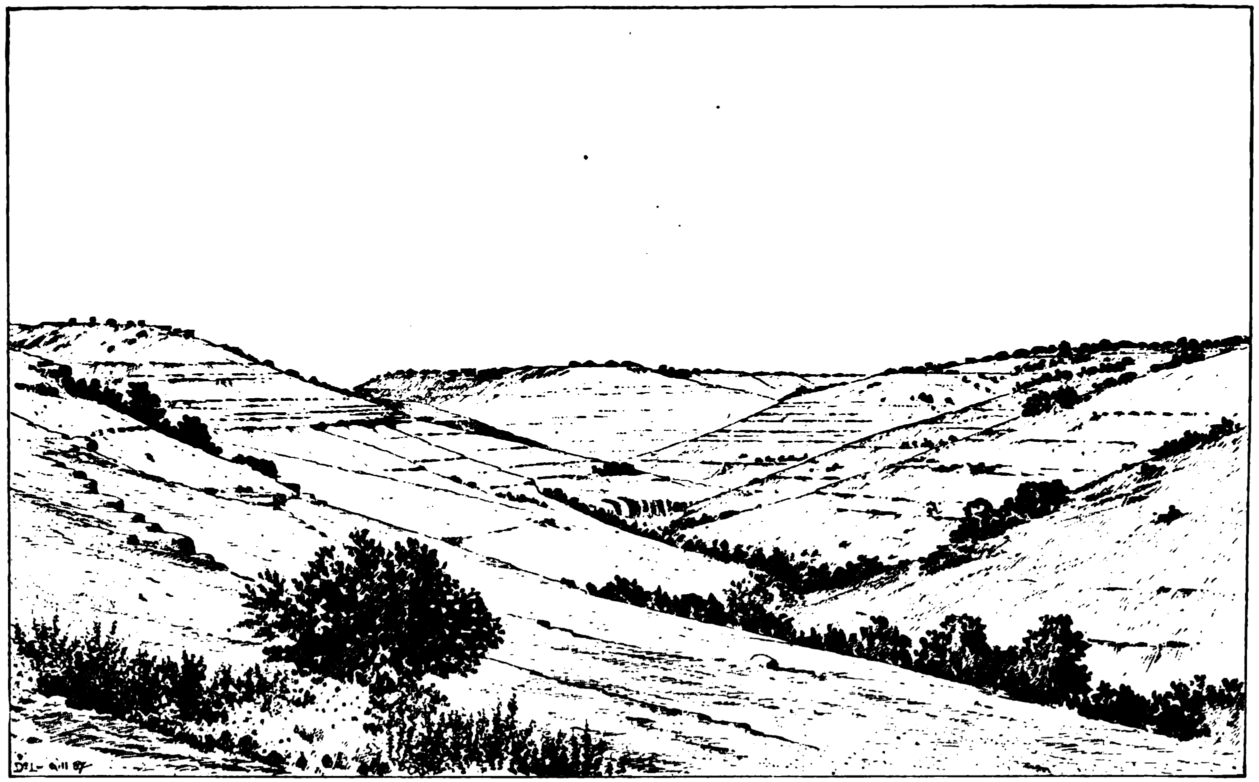
PLIOCENE.

Within the Lassen Peak district deposits of Pliocene age have not been definitely distinguished from those of the Miocene, but their presence is rendered altogether probable by several considerations. The auriferous gravels were regarded by Professor Whitney as accumulating upon the western slope of the Sierras throughout the whole of the Tertiary, reaching their culmination in the Pliocene. This view is very probable, indeed; for, although the mass of the gravels of the gold belt are Pliocene, it appears to be evident that other portions, especially that at Cherokee as well as about Mountain Meadows and near the head of Light Cañon, belong to the Miocene.

Overlying the Miocene of the Piedmont region is a very extensive development of the volcanic tufas. As already remarked, in the upper portion of the Miocene conglomerate, especially in the region of Bear Creek, Diamond Peak, and Mountain Meadows, pebbles of lava become abundant; in fact, they rapidly increase upwards, so as to completely predominate, and the formation passes into tufa without any apparent stratigraphic interruption. It has been completely demonstrated by Whitney, Le Conte, and others that in the Sierras the great volcanic outbreak took place in the Pliocene, and there is reason to believe that the early eruptions in the Lassen Peak district, which gave birth to the immense mass of tufa in the Piedmont region, occurred about the same time. The tufas were unquestionably deposited later than strata known to be Miocene, and earlier than the Quaternary, so that we feel constrained to regard them as belonging to the Pliocene.

This formation has its greatest development in the southwestern quarter of the Piedmont region and determines its peculiar features. All of the mountain streams between Battle and Butte Creeks on their way to the Sacramento have cut deep cañons across the Piedmont, and thus furnish excellent exposures of the tufa. Its genesis is a very perplexing problem.

The material of which it is composed is chiefly hypersthene andesite, but fragments of hornblende andesite and basalt are also common. Much of the detritus has been subjected to considerable water attrition, so as to appear in the form of rounded pebbles or sand; but the larger portion, ranging in size from fine dust to blocks of lava several feet in diameter, is rough and angular without distinct traces of abrasion. In the cañons where the tufa is well exposed it may be observed that much of the material is assorted and distinctly stratified. The accompanying illustration (Pl. XLVIII), which represents its general features very well, was taken near the western



CAÑON OF LITTLE DRY CREEK, SHOWING THE STRATIFIED TUFAS OF THE PIEDMONT REGION.

limit of the Piedmont, northeast of Tehama. It is true that in many places a stratum of material apparently thrown together pell-mell may be so large as to create the impression that the whole mass is without arrangement, but this is not the case. Much of the sediment has been picked out and laid down in such a way as to clearly indicate that its deposition took place in water. In the cañon of Mill Creek and also in that of Deer Creek, near the mountains, where the tufa has a thickness of nearly one thousand feet, it is roughly divisible into three parts, as indicated in Fig. 17. The upper and lower portions are agglomerate and between them the stratified arrangement of the tufa is clearly discernible. In all parts the sediments are essentially the same, being composed largely and perhaps chiefly of fragmental material ejected from volcanoes.

The peculiar manner in which the tufa was formed is an enigma whose complete solution has not yet been attained; nevertheless there are some conditions attending its formation which we may understand. The aqueous stratification of a large part of the tufa appears to me to be evident, and the body of water in which it was laid down filled the northern end of the Sacramento Valley. Piute Lake, with modifications, may have continued into the Pliocene. At any rate, it is apparent that the water body about the northern terminus of the Sierras during the Pliocene was shallower and more extensive than the Miocene Lake, and differed also in the character of its deposits. The distinctly assorted material is of two varieties: (1) That which has been considerably abraded and was produced by normal shore agents, and (2) that which was ejected during violent volcanic action and after being wafted for a considerable distance by the winds fell into the water.

The agglomerated portion of the tufa is complicated in its genesis, and probably received additions in various ways. Most important of these along its eastern margin was the tumultuous contribution from the active volcanoes near shore.

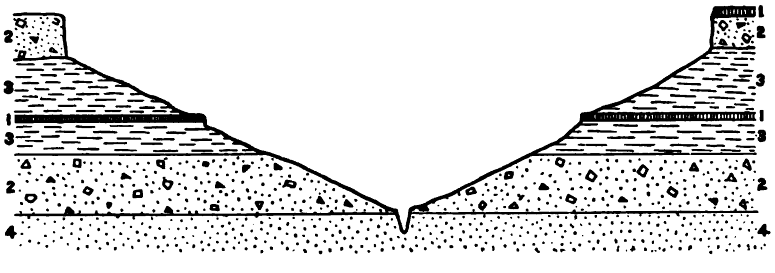


FIG. 17. Mill Creek Canon, 20 miles east of Tehama: Depth 1000 feet. 1. Basalt. 2. Agglomerated tufa. 3. Stratified tufa. 4. Yellowish sandstone.

Intercalary lavas such as are shown in the section (Fig. 17) are not uncommon, and by irregular decomposition and disintegration they frequently give rise to pseudo-agglomerates which may closely resemble real agglomerate in general aspect. They may be readily distinguished from the latter, however, by the uniformity of their composition throughout both matrix and fragments.

A large part of the pell-mell beds are heterogeneous in composition, and contain large angular fragments of compact lava, which bear no marks of having ever been ejected from a volcano, but appear rather to have been driven from their parent bed in the process of secular decay.

The manner in which superficial lava flows may be broken up by atmospheric influences and the angular fragments strewn over the plain is well illustrated by several examples in the Piedmont region, especially in the vicinity of Paine's Creek. This process is evidently subaërial and is doubtless accompanied to some extent by the sort of action which gives rise to alluvial cones. The cause which produces alluvial cones is the main one to which Captain Dutton appealed to explain the accumulation of the enormous detrital masses of volcanic rocks in the high plateaus of Utah,[1] and it has probably contributed to the upbuilding of the Piedmont region; but the greater influence in the development of its peculiar features must be ascribed to the Pliocene lake which occupied the northern part of the Sacramento Valley.

The topographic features which always accompany the degradation of heavy beds of agglomerate are often prominent, and enable the observer to recognize the formation at a considerable distance. They usually present either cliffs or irregular columns scattered promiscuously and abundantly over the slopes.

The plain of the Piedmont region is often extremely stony. The rough, angular fragments strewn over the surface in great numbers are in part the surviving pieces of a once continuous lava sheet, and in part the enduring portions of the disintegrating agglomerate, the finer material having been removed. A typic example of this sort of stony waste may be seen eight to twelve miles east of Red Bluff, south of Paine's Creek, on the Susanville road. The dreary plain is often for wide stretches without arboreal vegetation; but the stunted oak (*Quercus Garryana*), taking hold below, and the bull pine (*Pinus Sabiniana*) with the manzanita and other shrubbery above, mitigate its otherwise complete barrenness. The traveler over the desolate Piedmont region is not likely to forget its peculiarities, especially if he crosses it in an open conveyance under the blaze of a summer sun. It fits him to enjoy the salubrity of the mountain clime beyond, and it makes him feel that he has earned an abode for a time in the garden of the Hesperides by having successfully passed through Pandemonium.

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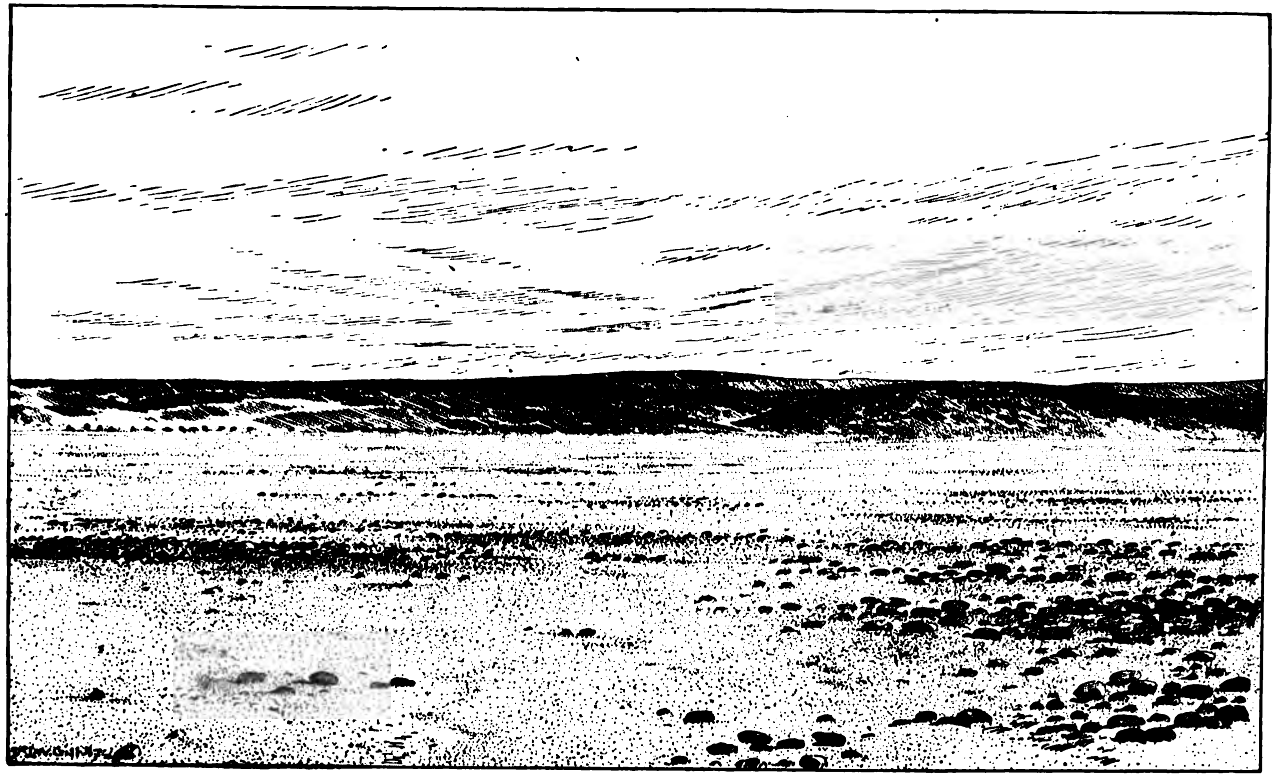
[1] Geology of the high plateaus of Utah (Capt. C. E. Dutton), 1880, p. 77



VIEW OF THE PIEDMONT BLUFF FROM THE SACRAMENTO VALLEY.

Lassen Peak volcanic ridge in the distance.

UPHEAVAL OF THE PIEDMONT REGION.

That the tufa of the Piedmont region was deposited near the shore of a large body of water which occupied the northern portion of the Sacramento Valley is apparently certain, and that the water was fresh is inferred from the fact that it appears to have been a continuation of the fresh-water Miocene lake. It is evident that the champaign character of the formation was determined by the water in which the deposition took place. Some time after the deposits were formed they were raised above the lacustrine waters in such a way that the mountain streams run directly across them and each stream excavated for itself a deep cañon. The uplifting was differential, being greatest to the eastward, so as to give the plain a westward declivity of about four degrees. At the same time the western limit of the region was defined by the development of an interesting monoclinal fold, which is exposed in the gates of all the cañons where the streams debouch into the Sacramento Valley proper. It gave rise to the prominent bluff which is well illustrated in the following view (Pl. XLIX), taken from the Sacramento Valley opposite the gate of Mill Creek. The bluff is here over a hundred feet high. Across the Piedmont region, at a distance of about twenty miles, the volcanic ridge of Lassen Peak is conspicuous. A section of the monoclinal fold south of Antelope Creek is given in Fig. 18, and shows the relation of the tufa of the Piedmont region to the Quaternary gravels of the Sacramento Valley. This monoclinal fold extends from the neighborhood of Battle Creek on the north beyond Deer Creek, gradually dying out at both ends, so that the Piedmont region beyond the limits of the fold continues its gentle slope without interruption to the level of the Sacramento Valley. The displacement along the monoclinal fold is on an average somewhat more than one hundred feet and was formed before the deposition of the Quaternary. At that time the cañons were already cut across the Piedmont, and the streams entered the Sacramento Valley at the level of its alluvial plain, to which each creek contributed a low, deltoid, gravel cone.

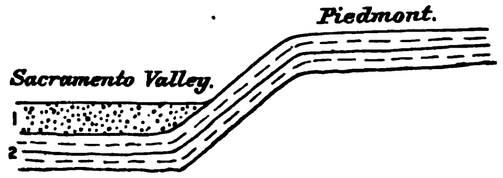


FIG. 18. Section of the Piedmont monocline near gate of Antelope Creek. 1 Quaternary gravels. 2. Volcanic tufa (Pliocene?).

Within the cañon of Deer Creek, as also in that of Mill Creek already illustrated (Fig. 17), there is a small cañon containing the present stream. It is best developed near the gate of Mill Creek, where the annexed view (Pl. L) was taken, The depth is frequently over seven times its width, and it extends out into the valley gravels for more than a mile. It is evident that this secondary cañon is due to the differential uplifting of the Piedmont region, by which the declivity of the stream was so increased as to augment the corrasion upon its restricted bed and in the same proportion to diminish the wearing away of its banks. The relation of the valley gravels to the Piedmont bluff, and the fact that the younger cañon extends some distance out into the Quaternary deposits indicate that the latest uplifting in that region, which gave birth to the little cañon, was post-Quaternary, although the formation of the monocline took place at the close of the Pliocene.

STRUCTURE OF THE SIERRAS..

That the development of the Sierras and their relation to the volcanic ridge of Lassen Peak may be more readily understood, some of the more salient structural features of the northern portion of the range will be briefly considered. It has a width of about eighty miles, extending from the Sacramento Valley to Honey Lake, and has three distinct crests which are characterized by long, gentle slopes to the southwest, and short, abrupt ones in the opposite direction, as shown in Fig. 19. The western crest, to which Claremont Hill and Spanish Peak belong, is near the middle of the range, and attains an altitude of about seven thousand feet. From this point the long, gentle slope extends to the Sacramento Valley, at an elevation of less than three hundred feet above the sea. It is more or less undulating and deeply cañoned by numerous streams. From Claremont Hill the slope is abrupt towards American Valley, which at Quincy has an altitude of 3,375 feet. Continuing to the eastward the slope again rises more gently 7,300 feet to the middle crest, in which Hough's Mountain is a prominent feature, and then descends steeply, as in Pl. LI, to Indian Valley, at an elevation of about thirty-five hundred feet. Farther on the topography is irregular, but becomes an even slope, rising to 6,000 feet in the summit of the eastern crest, the bold escarpment overlooking Honey Lake. The outline of the Sierra Nevada Range, as seen in cross-section, is such as to at once suggest that, like the basin province, it is composed of tilted orographic blocks, which are separated from one another by faults. The fact that Indian Valley and American Valley, which are the depressions between the crests of the range, were occupied

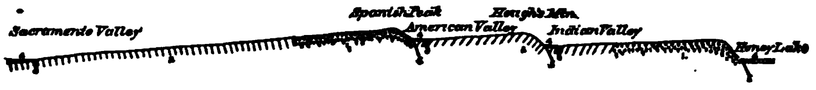
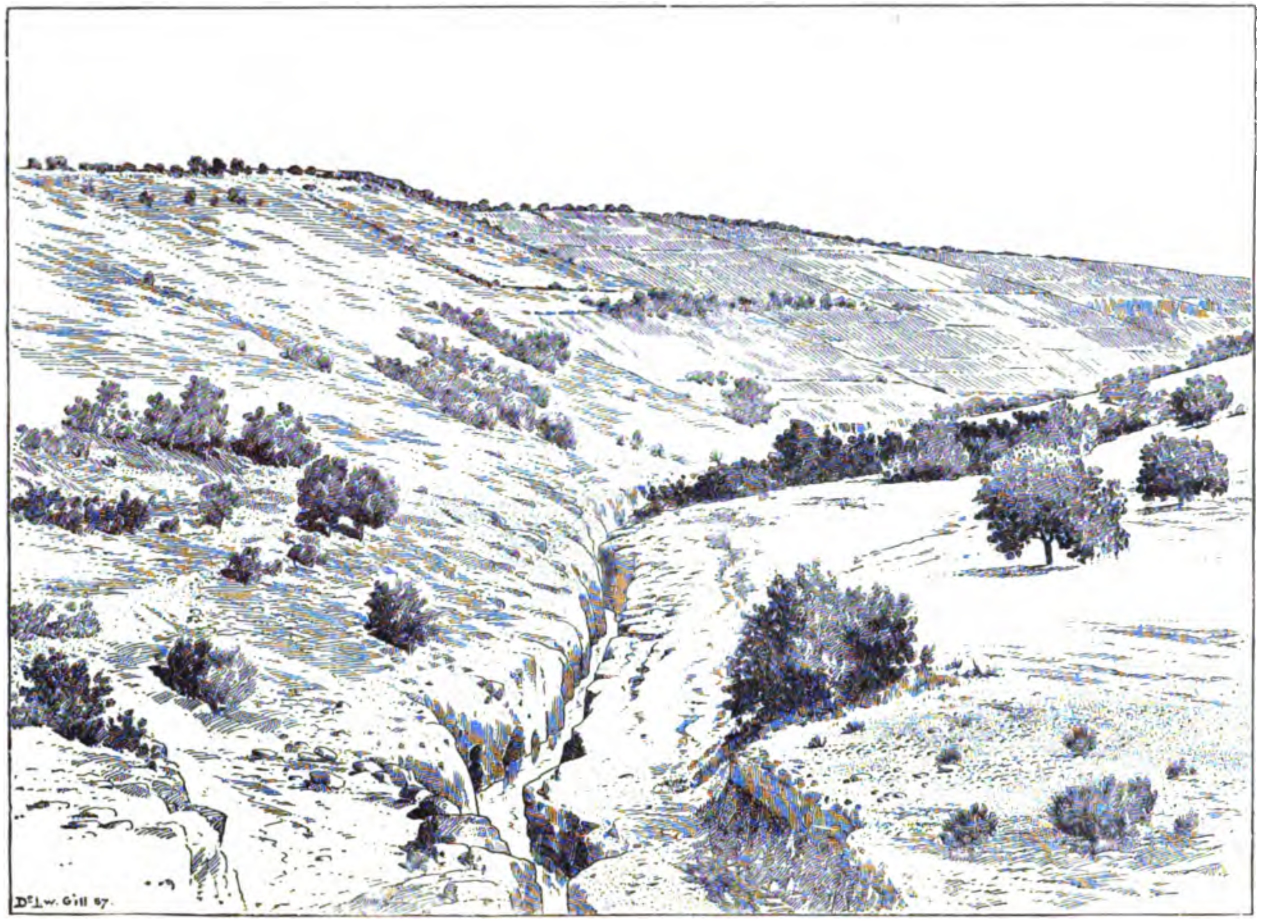


FIG. 19. Section from Honey Lake to Sacramento Valley. 1. Granite. 2. Auriferous slates. 3. Carboniferous limestone. 4. Quaternary, or recent deposits. 5. Faults.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VIEW SHOWING THE RELATION BETWEEN OLDER AND YOUNGER CAÑONS OF MILL CREEK.

Eight miles east of Tehama.

by lakes during the Quaternary or later times greatly heightens the analogy.[1]

The recurrence of the same fossiliferous strata in a cross-section of the Sierra Nevada Range in exactly analogous topographic and stratigraphic positions confirms the hypothesis suggested by the profile that the northern end of the Sierra Nevada Range is made up of three orographic blocks separated from one another and from those of the Great Basin by profound faults, and shows that the basin range structure extends as far west as the Sacramento Valley. Mr. G. K. Gilbert[2] several years ago pointed out the characteristic features in the structure of the Sierra Nevada Range. Prof. Joseph Le Conte[3] had previously called attention to a profound fault along its eastern base in the vicinity of Owen's Lake, and has since published a most interesting contribution[4] on a post-Tertiary elevation of the Sierra Nevada shown by the river beds.

By far the greater portion of the range appears to be formed of one great orographic block, which is continuous with the western block of the range at its northern termination. Its long, gentle slope westward is expressed in the drainage lines, and its eastern crest is the divide between the Great Basin and the Pacific. Almost throughout its whole extent the Sierra Nevada faults of greatest dimensions are impassable to important streams except at the northern end of the range, where the number of fault blocks is increased. The forks of Feather River cross two of the prominent lines of displacement. These streams, like nearly all those that flow down the western slope, are in deep cañons. That of the North Fork of Feather River, where it crosses the western fault, has a depth of 4,000 feet, affording an excellent section of the folded strata, and its terraces indicate the character of the uplifting in forming the mountain range.

Structurally the Sierra is like the Great Basin range, differing chiefly in the magnitude and the present elevation of the blocks. Like the orographic blocks of the Great Basin area, they are composed of plicated strata, the folding of which, as has been pointed out by a number of observers, took place long before the faulting that gave birth to the peculiar features of the range. It is important to remember the fact that at the time the strata of which the Sierra is composed were folded (i. e., about the limits between the Jurassic and Cretaceous periods) the range was not differentiated from the continental mass of the Great Basin region, and it was not until a very much later period that this separation occurred.

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[1] For remarks upon the stratigraphy of the orographic blocks, see Bull. U. S. Geol. Survey, No. 33, pp. 12–15.

[2] Science, vol. 1, 1883, p. 195.

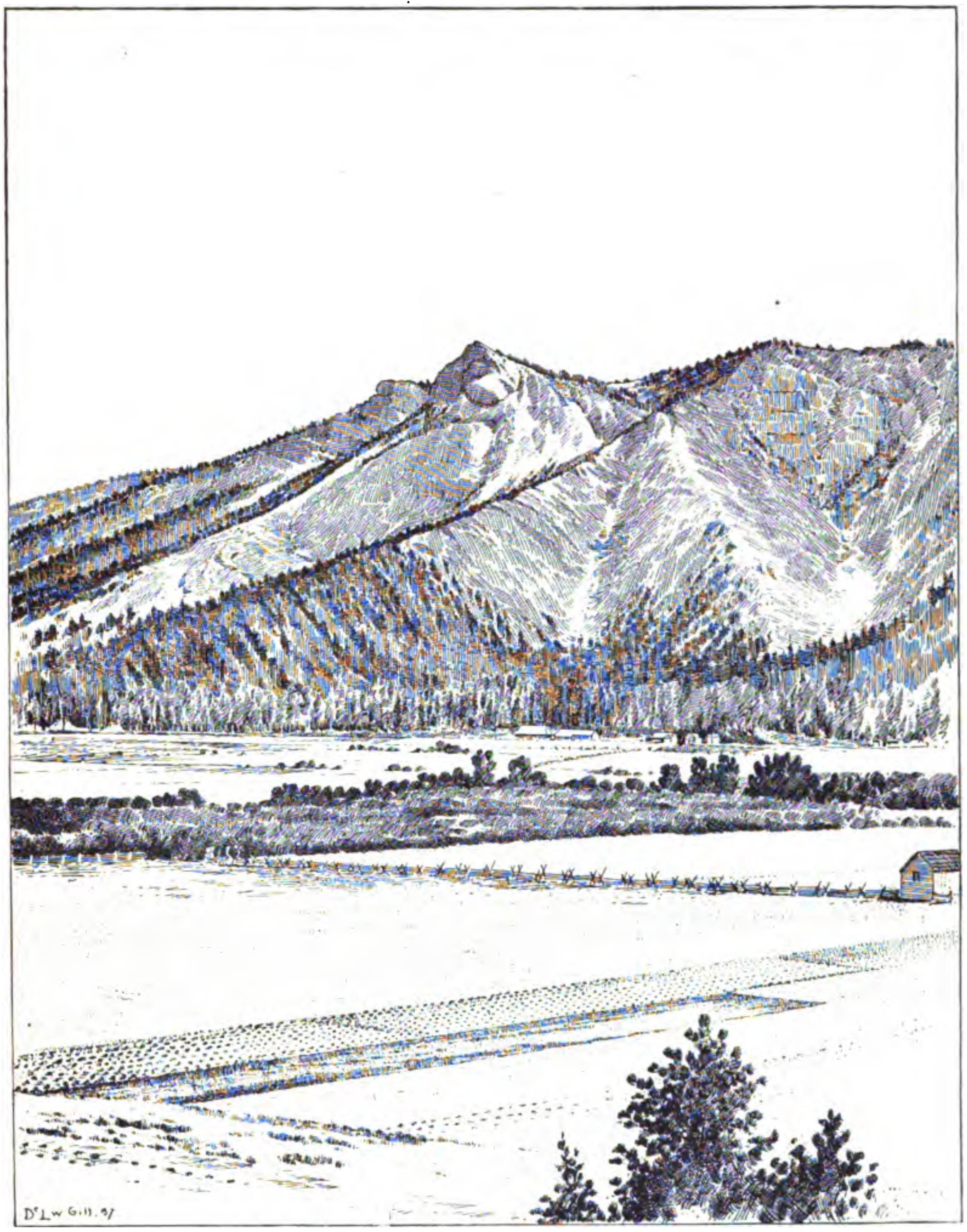
[3] Am. Jour. Sci., 3d series, vol. 16, 1878, p. 101.

[4] Ibid., vol. 32, 1886, p. 167.

It must not be imagined that the structure of the Sierra is really as simple as it appears in Fig. 19; for, as already stated, the auriferous slates and numerous eruptive masses of which the orographic blocks are composed are not only folded in a very confusing manner, but are greatly complicated also by a large number of recent faults. The uplifting of the Sierras resulted in the increased declivity of their western slope and caused the streams more and more vigorously to corrade their beds. Each successive uplift increased the corrasion and restricted the stream to a narrower channel, leaving terraces upon the slopes of the cañon to mark the time of the uplifting. Thus it happens that the western slope, once gentle and flooded by Pliocene streams, is now deeply furrowed by terraced cañons.

RELATION OF THE UPLIFTING AND FAULTING OF THE SIERRAS TO EACH OTHER AND TO VOLCANIC PHENOMENA.

The relation of the uplifting of the Sierra Nevada Range to its volcanic activity and faulting is one of the most important problems that the district affords, and its solution can not be fully attained until the detailed survey of districts adjacent to that of Lassen Peak is complete. During the whole of the Cretaceous and the Tertiary the great belt of country lying east of the present Sacramento Valley embracing the region now occupied by the Sierra, and a large portion of the Great Basin, was above the sea, and subjected to great degradation, which reduced it almost to its base level of erosion. This gentle plain swept westward toward the ocean directly across the site of the present Sierra. That the north end of the Sierra country was a lowland during the Miocene, as already shown, is rendered perfectly evident by the character of its flora; and the relation of the Miocene conglomerate to the eastern escarpment north of Honey Lake is such as to demonstrate that during the Miocene the Sierras were not yet in existence. Similar conditions continued through the Pliocene, for the Pliocene gravels on the western slope of the Sierras were evidently deposited while its inclination was very gentle, before the Sierra region had attained any considerable elevation, and apparently also while it was yet a part of the Great Basin platform. The long continued repose of that region was terminated by the development of vigorous volcanic activity, accompanied by extensive upheaval. That these two phenomena developed contemporaneously is made plain by the relations of the volcanic products to the Pliocene and Quaternary river channels. It is well known that the Pliocene channels were filled with volcanic débris and lava flows to such an extent that the streams had to seek new channels. The differential uplifting which accompanied the volcanic outbursts greatly increased the erosive power of the streams, and the result is to be seen in the deep cañons which they have cut down the western slope of the Sierras, leaving the ancient beds of the Pliocene streams



HOUGH PEAK, LOOKING SOUTH ACROSS THE WESTERN PORTION OF INDIAN VALLEY.

on the divides far above the present water ways. That the uplifting of the Sierras was not all accomplished at once but by a succession of upheavals separated by considerable intervals of time is evidenced by the traces of stream terraces which can be detected along the slopes of the cañons. These have the same origin as that already considered in describing the Piedmont region (page 426), and are undoubtedly due to successive increase in the declivity of the western slope produced by differential elevation. Now, it not infrequently happens that the lava erupted at the time of the uplifting has flowed down a cañon and capped the terrace formed at that time. That the terrace is due, not to the lava flow, but to the upheaval, is readily perceived by following the flow to its lower extremity, where the terrace upon which the lava rests will be found to continue far beyond the lava stream itself. While it can not be demonstrated that each volcanic eruption was accompanied by a corresponding elevation, it appears to be generally true that each great upheaval was accompanied by volcanic outbursts. Numerous examples of the contemporaneity of upheavals and volcanic effusion indicate that they may be casually connected.

The faulting by means of which the Sierra Nevada Range was separated from the Great Basin platform took place, in a geologic sense, very recently. The eastern escarpment of the range, at least in its northern portion, was evidently formed after the conclusion of the volcanic activity in its immediate vicinity. Attention has already been called to the displacement of very recent lavas along the crest north of Honey Lake. Opposite Janesville, on the very brow of the eastern escarpment, is Thompson Peak, which is half of a crater cone cut in two by the fault; the other half has fallen away. The bedded tufas of the elevated remnant of the cone are a very conspicuous topographical feature on the crest, and their relation to the displacement is unmistakable. Thompson Peak was an active volcano during a very late geologic epoch, so recent indeed that notwithstanding its destructibility and exposure it has suffered comparatively little from erosion. Farther northward along the same crest other new basaltic flows have been profoundly dislocated in the same manner. The great mass of gravel which forms a smooth, barren ridge on the crest southeast of Diamond Peak was evidently formed before the faulting occurred. Its upper portion is composed chiefly of pebbles of modern lavas, indicating clearly that the volcanic activity antedated the dislocation. I have searched in vain along the eastern escarpment north of Honey Lake for volcanic material the eruption of which succeeded the faulting.[1]

The great fault which lies along the western side of American

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[1] In the vicinity of Lake Mono, however, and perhaps also at other points along the eastern base of the Sierras, there has been very recent volcanic activity, apparently subsequent to the displacement.

Valley continues northwesterly with irregularities into the modern lavas about the head of Butte Creek. At a number of other points north and east of Big Meadows there are lines of dislocation parallel with those of the Sierras and probably formed at the same time. They intersect some of the latest lava flows of that region and were evidently developed long after the volcanic activity had passed its maximum. Not a single example has been found of the escape of lava through a fault fissure.

This subject will be more fully discussed at another time, while considering in detail the volcanic phenomena of the Lassen Peak district. Enough has been said to make it evident that the volcanic activity upon the northern end of the Sierras occurred at the time of their upheaval and that the faulting and subsidence of the Great Basin region which individualized the range took place at a later date.

RECAPITULATION.

The primary relief features of the district are the Great Basin platform upon the east, the Piedmont region upon the west, and the Lassen Peak volcanic ridge in the middle. To the southeastward this ridge appears to merge into the Sierras, and in the opposite direction to unite with the Coast Range, but in reality it is simply an accumulation of lavas occupying a depression between these ranges and belongs geologically to the Cascade Range.

The stratified deposits, excepting the most recent lake beds, lying for the most part beneath the lavas belong to three groups, the auriferous slates, the Cretaceous member of the Chico-Tejon series, and the Tertiary, including both Miocene and Pliocene.

The auriferous slate series, which embraces both massive and water-laid rocks, occupies two areas at opposite extremes of the district, one in the vicinity of the North Fork of Feather River and the other near Pit River. The former is at the northern terminus of the Sierra Nevada Range, where the gold-bearing rocks are extensively developed, and the latter is at the end of the eastern extension of the Coast Range. Between these two exposures there is a great depression in the auriferous series transverse to the general trend of the Sierras. This depression marks the boundary between the northern end of the Sierras and the Coast Range, and from the latter portion of the Cretaceous to the Pliocene, inclusive, was occupied by Lassen Strait, which filled it with sediments.

Among the auriferous slates there are large masses of serpentine which have resulted from the alteration of peridotites, in some cases so rich in olivine that they may be classed with the dunites.

Concerning the age of the auriferous series it may be said that, as it becomes more and more evident that a large part of the auriferous slates is Mesozoic, so also the evidence is accumulating in favor of the view that another large portion of them is older than the limestone and possibly pre-Carboniferous.

The Chico beds laid down as marine sediments are the most ancient, unaltered, stratified rocks known in the district and repose discordantly upon the plicated auriferous slates. They occupy the great central valley of California and, extending through Lassen Strait, connect with a large mass covering a wide expanse in eastern Oregon. During the Chico epoch the Lassen Peak district lay almost wholly within Lassen Strait, which separated the large Cretaceous island of northwestern California from the continental land to which the Sierra country belonged.

Some time between the close of the Chico epoch and the beginning of the Miocene there was an upheaval west of the Sacramento Valley, and also apparently in the vicinity of the Cascade Range. The oceanic waters were thus excluded from the Sacramento Valley, Lassen Strait, and a large area in eastern Oregon, for we find that the whole region of Upper Cretaceous marine sediments was covered during the Miocene by a great body of fresh water, to which the name Piute Lake has been given. Whether the transition from marine to fresh water conditions was direct or, as at other places, through a series of intermediate brackish water stages, is as yet only conjectural. Positive evidence concerning the history of the district during the latter portion (Eocene) of the Chico-Tejon period has not been clearly made out, but it may be surmised that if the moderate upheaval which gave birth to Piute Lake occurred at the close of the Chico epoch the equivalent of the marine Tejon deposits may be looked for in the lower portion of the Piute Lake beds.

Before the Miocene there was a change in the relative elevation of the Sacramento Valley and the Sierra region, because the shore deposits of Piute Lake are found farther up on the slopes of the Sierras than those of the Chico group. This change was doubtless a part of the result brought about by the movement which raised the Sacramento Valley above the sea level and prepared the slightly unconformable surface for the Piute lake deposits.

The relations of the Miocene lacustrine deposits appear to fully justify the statement that at the time they were laid down part of the Great Basin country was higher than the region now occupied by the Sierras, at least in the latitude of Diamond Peak. During the Miocene that country was a broad platform, with the gentle relief that indicates a near approach to its base level of erosion. The evidence drawn by paleobotanists from the plant fossils found in the Miocene strata strongly corroborates this view. They have compared the climatic conditions of that country during the Miocene to those of a country like Florida.

The Miocene conditions appear to have continued into the Pliocene, at least as far as Piute Lake is concerned, and to have finally terminated in a great revolution which gave to the country its present aspect.

The extravasation of massive rocks occurred at various intervals in the geologic history of northern California, but the final great volcanic outburst reached its maximum near the close of the Pliocene and continued with gradually declining vigor almost to the present day.

The upbuilding of the Lassen Peak volcanic ridge was effected by these outbursts, and at the same time birth was given to the material from which the Piedmont region was developed at the close of the Tertiary. This material was deposited chiefly under the influence of lacustrine waters, and upheaved bodily in such a way as to produce a monoclinal fold and bluff which marks the western limit of the Piedmont region.

Since the deposition of the Quaternary gravels of the Sacramento Valley there has been a differential uplifting of the Lassen Peak district, by which the streams crossing the Piedmont have been enabled to cut small cañons within the larger ones of pre-Quaternary corrasion.

Gentle slopes prevailed during the deposition of the Pliocene gravels. The uplifting of the Sierras took place for the most part at the close of the Pliocene, and was accompanied by the manifestation of great volcanic activity.

The profile of a cross-section of the Sierras and the recurrence of the same fossiliferous strata in analogous topographic and stratigraphic positions demonstrates that the northern end of the range is made up of three orographic blocks separated from one another and from those of the Great Basin by profound dislocations. These displacements occurred chiefly if not wholly after the elevation of the Sierras, when the volcanic energy had almost spent itself. The Sierras were made to appear as a distinct range by the subsidence of the Great Basin region.

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